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LAPWORTH, C. 1878. The Moffat Series. *Quart. Journ. Geol. Soc.*, xxxiv, 240–343.

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GEOLOGICAL MAGAZINE

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Downtonian (Silurian) Eurypterida from Perton, near Stoke Edith, Herefordshire

By ERIK N. KJELLESVIG-WAERING (Tulsa, Oklahoma)

(PLATES I–III)

ABSTRACT

In this review of the Downtonian Eurypterida of Perton, Herefordshire, a new genus *Salteropterus* and a new family Hughmilleriidae are proposed, and the family Pterygotidae accordingly emended. Hitherto unknown morphological details of the Perton Eurypterida are described and discussed.

I. INTRODUCTION

EURYPTERIDS from the lower Downtonian beds at Perton, near Stoke Edith, Herefordshire, were discovered by the Rev. P. B. Brodie, who communicated a short note on the presence of *Eurypterus* and *Pterygotus* to the Geological Society in 1869. The specimens collected at that time were submitted to Henry Woodward, who reported that for the most part they consisted of fragments of *Pterygotus banksii* (Salter), *Eurypterus pygmæus* Salter, *Eurypterus acuminatus* Salter, and *Eurypterus abbreviatus* Salter. Further collections were made by the Rev. Brodie resulting in the discovery of a new form which Woodward described and figured under the name *Eurypterus brodiei* (1871, p. 261). No further attention has been given in the literature to the eurypterids from Perton since Woodward's notice in 1871.

The present writer became interested in these eurypterids during an investigation of *Eurypterus* and allied forms. Inasmuch as the original figure and description of *Eurypterus brodiei* Woodward presented several characteristics of a puzzling nature, he borrowed part of the Brodie Collection from the Geological Survey, and obtained photographs and a cast of the holotype of *E. brodiei* from the British Museum (Natural History). These revealed several features of considerable interest and Dr. C. J. Stubblefield consequently made available the entire Brodie Collection as well as an important collection made by Dr. R. W. Pocock and A. J. Butler which had been presented to the Geological Survey in 1939. In total about seventy-five specimens are included in both collections.

As a result of this review of the Brodie Collection and the specimens collected by Pocock and Butler, *Hughmilleria banksii* (Salter) becomes as well known morphologically as the Norwegian *H. norvegica* (Kiaer)

and the American *H. socialis* Sarle and *H. shawangunk* Clarke, and the writer has proposed a new family, herein named the Hughmilleriidae. It seems highly probable that the specimens recorded by Brodie (1869, p. 236) as *Stylonurus megalops* (Salter), which he reported as the commonest eurypterid collected, are *Hughmilleria banksii.* The present writer was also unable to find either *Hughmilleria acuminata* or *Hughmilleria* ? *pygmæa,* and it is suggested that the forms identified as *H.* ? *pygmæa* are the small, immature specimens of *H. banksii.*

The form previously known as *Eurypterus abbreviatus* Salter has been included in a proposed new genus, *Salteropterus.* A complete telson collected by Pocock and Butler, and not available to Woodward, reveals the unusual characteristics of this unique form. Several fragments of a very large *Pterygotus* were included in the collections, but only a metastoma could definitely be assigned to *Pterygotus gigas* Salter. *Eurypterus brodiei* Woodward is redescribed, as part of the original description and figures represented a composite of both *Eurypterus brodiei* and *Hughmilleria banksii.*

Fragments of *Carcinosoma* sp., *Mixopterus* sp., and a peculiar eurypterid, designated as *Tarsopterus* ? sp., also were noted in the collections from Perton.

In comparison with other faunas the eurypterids of the Downtonian of Perton resemble most the Pittsford assemblage of New York. *Hughmilleria banksii* is in many respects like the genotype *H. socialis* Sarle. The rest of the forms, with the exception of the very unusual *Salteropterus abbreviatus* and *Tarsopterus* ? sp., bear some resemblance to the New York eurypterids. The writer, however, does not suggest a correlation, for in his opinion our knowledge of Eurypterida is too meagre to warrant anything but general correlations over any great distance. In this connection it is important to note that the eurypterid assemblages found in the Bertie (Silurian) waterlime of western and central New York are quite different : both are found in apparently the same environment and are not separated by any considerable distance.

In comparison with the Downtonian eurypterids of Scotland, no common basis exists and likewise with regard to the Downtonian of the Ringerike area of Norway, so ably described by Størmer (1934), no species is common to either fauna. However, the peculiar and inconclusive fragment referred to *Tarsopterus* ? sp., bears considerable resemblance to a fragment reported by Størmer : both apparently belong to the same genus, although probably different specifically.

Horizon and locality : The eurypterids at Perton are fragmentary, but the preservation is unusual in showing delicate details such as the bristles of the epicoxite and the minute facets of the lateral eye in *Hughmilleria.* In many cases the thin test of the eurypterids can be

lifted off the shale matrix and appears flexible, brown in colour, and not unlike the original chitin. Nearly all the specimens studied were preserved in olive-green, soft, micaceous shale. Some were found in sandy shales and one specimen in sandstone.

Symonds (in Woodward, 1872, p. 100) reports an exposed section of nearly 17 feet of shales resting on sandstone at the quarry at Perton. The eurypterids are of lower Downtonian in age, occurring in " olive " shales at the base, and also within the sandstone. Land plants are commonly intermingled with the eurypterid fragments.

The Brodie Collection is registered under numbers 5996–6003, 88906–88914, and Zi-3932–3965. The Pocock and Butler Collection is registered as Zf-2861–2872, 89628–89629, and Zi-4579–4581. A single specimen of *Hughmilleria banksii* (Salter) (collector unknown) is registered as 83880. All specimens are in the collections of the Geological Survey and Museum.

The writer is particularly indebted to Dr. C. J. Stubblefield, of the Geological Survey and Museum, for the loan of the collections reported here, and wishes also to thank Mr. R. Baker, of the British Museum (Natural History), for the excellent casts and photographs of *Eurypterus brodiei* Woodward.

II. Classification

At the present time the Eurypterida are divided into four families, Pterygotidae (Clarke and Ruedemann, 1912), Eurypteridae (Burmeister, 1843), Carcinosomidae (Størmer, 1934), and Stylonuridae (Diener, 1924). Approximately 190 species have been described, of which slightly less than half are included in the family Pterygotidae. Generally included in the Pterygotidae are the genera *Pterygotus*, *Hughmilleria*, *Slimonia*, *Hastimima*, *Grossopterus*, and *Lepidoderma*.

The families are separated mainly on the characters of the ventral appendages. On this basis it is apparent that the development of very long, preoral appendages, or chelicerae, with large teeth on each chela, as well as the fragile, slender, and cylindrical walking legs, devoid of spines, and comparable in length, are features which separate *Pterygotus* from *Hughmilleria*, *Slimonia*, *Grossopterus*, and *Lepidoderma*. The latter genera have small simple chelicerae, and their walking legs are developed as stout structures increasing in size progressively backwards, and armed with either spines or spurs. The writer therefore suggests the establishment of a new family, the Hughmilleriidae, named after the best known and most common genus, *Hughmilleria*.

Family HUGHMILLERIIDAE nov.

Dorsal shield with small compound eyes, marginal or subcentrally located; epistoma large, antelateral shields, narrow; chelicerae

simple, without teeth, small; walking legs stout, increasing progressively in size backwards, with spines or spurs; swimming paddles developed; surface sculpturing of semilunar scales or pointed mucrones.

It is suggested that the genera *Hughmilleria*, *Slimonia*, *Grossopterus*, and *Lepidoderma* should be included in this group. The genus *Hastimima*, as yet very imperfectly known, may belong here, and the new genus *Salteropterus*, described below, is also referred to the Hughmilleriidae.

Family PTERYGOTIDAE Clarke and Ruedemann emend.

Dorsal shield with large marginal compound eyes; epistoma large, antelateral shields, broad; chelicerae large and very long, with numerous large teeth on each chela; walking legs very slender, approximately of the same size; cylindrical, devoid of spines or spurs; swimming paddles developed; surface sculpturing of broad, scale-like markings.

As thus restricted this family only includes the genus *Pterygotus*. Previously slightly over eighty species composed this family. Approximately half of these have now been transferred to the Hughmilleriidae. It is not within the scope of this paper to discuss the various taxonomic problems of the Pterygotidae or the number of possible genera into which the Pterygotidae could be divided.

III. Description of Species

Family HUGHMILLERIIDAE Kjellesvig-Waering nov.

Genus Hughmilleria Sarle 1903

Hughmilleria banksii (Salter)

Pl. I; Pl. II, Figs. 1–5; text-fig. 1; 2A, B

Himantopterus banksii Salter, 1856a, pp. 32–3.
Himantopterus banksii Banks, 1856, p. 99, pl. ii, figs. 5, 6.
Himantopterus banksii Salter, 1856b, p. 266, foss. 66, fig. 1.
Pterygotus (*Erettopterus*) *banksii* Salter, 1859a, pp. 51–3, pl. xii, figs. 22, 24–9, 31–5, 39, 41–4 (not 23, 30, 36–8, 40, 45–6).
Pterygotus banksii Salter, 1859c, p. 540.
Pterygotus (*Erettopterus*) *banksii* Bigsby, 1859, p. 322.
Pterygotus banksii Salter, 1867, p. 239.
Pterygotus banksii Woodward, 1871b, p. 261.
Eurypterus brodiei (part) Woodward, 1871b, pp. 262–3 (in part), figs. 2, 3.
Pterygotus banksii Woodward, 1872 (1866–1878), pp. 72–4, pl. xvi, figs. 2, 3, 5, 6 (not fig. 4).
Eurypterus brodiei (part) Woodward, 1872, pp. 162–3 (in part), fig. 51 (2, 3).
Pterygotus banksii Salter, 1873, p. 189.
Pterygotus banksii Woodward, 1877, p. 67.
Pterygotus banksii Etheridge, 1888, p. 66.
Pterygotus banksii Sarle, 1903, p. 1103.
Pterygotus banksii Elles and Slater, 1906, p. 220.

Pterygotus (*Erettopterus*) *banksii* Clarke and Ruedemann, 1912, p. 379.
Pterygotus (*Erettopterus*) *banksii* O'Connell, 1916, p. 47.
Pterygotus (*Erettopterus*) *banksii* Diener, 1924, p. 10.
Hughmilleria banksii Størmer, 1934b, p. 83.
Pterygotus banksii King, 1934, p. 563.
Hughmilleria banksii Størmer, 1934a, p. 4.
Hughmilleria banksii Kjellesvig-Waering, 1950, p. 228.

Not *Hughmilleria banksii* (Salter)

Pterygotus banksii Salter, 1859a, pl. xii, figs. 23, 30, 36–8, 40, 45–6 (= *Pterygotus* sp.).
Pterygotus banksii Woodward, 1872 (1866–1878), pl. xvi, fig. 4 (= *Pterygotus* sp.).

Salter (1856a, p. 32) described a eurypterid from the Downtonian at Kington, Herefordshire, under the name *Himantopterus banksii*. No figures were given with the original description. The same year Banks (1856, p. 99) figured three prosomas, a telson, and two tergites of Salter's previously described species. It seems that both authors agreed to have the figures in Banks's paper, although no mention was made of the arrangement by either, but in a subsequent paper Salter (1859, p. 51) refers to Banks's figures as part of his original description.

In Salter's Monograph (1859, p. 51) the name of the species was changed to *Pterygotus banksii* and placed under the subgenus *Erettopterus*. Numerus figures of additional specimens were introduced, of which a number were erroneously ascribed to the species. These figures are comprised of parts of the chelicerae and several telsons of a *Pterygotus*, and have no relation to the original *H. banksii*. In the same publication Salter erroneously referred the telson, figured by Banks (1856, fig. 6), to *Eurypterus*. This telson is very likely part of *Hughmilleria banksii*. Woodward (1872, p. 72) followed Salter's (1859, p. 51) later treatment of the species, including parts of a true *Hughmilleria* along with parts of a *Pterygotus* under the species *P. banksii*.

The species therefore became established in the literature as *Pterygotus banksii* (Salter) until Størmer (1934, p. 82) correctly referred it to the genus *Hughmilleria*, and noted that some of the parts figured by Salter and Woodward represented a *Pterygotus*. Later Størmer (1936, p. 41) referred to the parts which belonged to *Pterygotus*, and which Salter (1856, pl. xii, figs. 23, 30, 36–8, 40, 45–6) had erroneously included under *P. banksii*, as *Pterygotus* (*Erettopterus*) *banksii*. The name *banksii* cannot be used for a species of *Pterygotus*, inasmuch as Salter's inclusion of these parts was a misidentification. The original description and figures of the species represents a single form, *Hughmilleria*. The *Pterygotus* later figured by Salter appears to be a unique and, at present, unnamed form, and can only be known as *Pterygotus* sp., as the name *Pterygotus banksii* is preoccupied.

Woodward (1871, p. 261) reported the presence of *Eurypterus* (= *Hughmilleria* ?) *pygmæus* in the Brodie Collection. The present writer has not been able to find any trace of this species in the Perton material, either in the Brodie Collection or the specimens collected by Pocock and Butler. In the Brodie Collection, however, are a number of immature specimens of *Hughmilleria banksii*, some of which had labels identifying them as *Eurypterus pygmæus*. It is uncertain who made these determinations, and while direct documentary evidence is lacking as to what specimens Woodward thought represented *Eurypterus pygmæus*, it seems probable that the immature forms of *Hughmilleria banksii* may be the basis of Woodward's *Eurypterus pygmæus*.

Hughmilleria banksii (Salter) is a robust form of the genus, and very much like the genotype *H. socialis* Sarle from the upper Silurian, Pittsford shale of New York. Adult individuals have an overall length of approximately 180 mm. It is the commonest eurypterid encountered in the lower Downtonian at Perton.

Description

Prosoma.—Semi-elliptical to subtriangular in general aspect, slightly broader than long. Lateral margins straight, parallel to each other, and gently curving inward at the posterior portion of the large compound eyes. The antero-lateral angles are broadly rounded and meet at the anterior margin where a gentle but diagnostic protuberance of the carapace is present. The frontal protuberance is normally slightly bent downward. The base of the prosoma is straight except towards the posterior angles where it is curved gently forward to join the lateral margins at an obtuse angle. It may be that in life the base met the lateral margins at right-angles, as the prosoma had considerable relief and the margins were steeply inclined.

The marginal rim is very narrow at the posterior angles, continuing forwards as a raised and rounded structure, which gradually flattens and widens along the anterior edge and along the protuberance of the anterior margin, where it measures 1 mm. in width (Zf-2866). The widening of the rim, as well as the angle formed by the change in direction of the rim at the anterior protuberance serves to accentuate the latter feature (see Text-fig. 1A). Fine striations were noted on the inner side of the marginal rim.

Though not entirely complete, enough is present to enable accurate measurements :—

	Width at Base.	*Width behind Eyes.*	*Length.*
	mm.	mm.	mm.
88909 . .	28·0	26·0	27·5
Zf-2866 . .	33·0	31·0	27·6
Zi-3949 . .	35·0 (estimated)	33·0	29·0

The compound or lateral eyes are large and elongated, between one-fourth to one-third the length of the prosoma. They are located at the margins and forward of the centre in the crushed specimens studied but probably occupy a submarginal position as in *Hughmilleria socialis* Sarle. As seen in the crushed specimens the posterior and anterior ends of the eyes at least do not touch the margins and are rounded at each end. Palpebral lobes were not developed. In one specimen (Zf-2866) the compound eyes measure 8·5 mm. in length and 3·0 mm. in width ; in another (88909) they measure 8·1 mm. and 3·5 mm. respectively. Ommatidia were preserved in only one specimen, which was freshly broken from the matrix (89629). These structures are extremely small, measuring more than 100 to the square millimetre.

The ocelli are prominent, each surrounded by a narrow, low rim, and are located at a line joining the posterior ends of the compound eyes, and are thus approximately central. The ocellar mound was not noticeable on the rather flattened specimens. Each median eye measures less than one millimetre in diameter and the pair is separated by slightly less than that amount. In specimen Zf-2866 they are located 12·0 mm. from the base, 14·5 mm. from the anterior margin, and 14·5 mm. from the lateral margins. In another specimen (5997) they are 13·5 mm. from the base, 13·5 mm. from the anterior margin, and 11·2 mm. from the lateral margins.

The surface appears to be devoid of ornamentation except for very small semi-lunar scales which are more apparent internally than externally.

The underside of the prosoma is known in considerable detail, although the doublure was not found. The general similarity of *Hughmilleria banksii* to the American *H. socialis* suggests that this structure also may prove comparable.

The appendages of the prosoma are not well known except for the swimming leg, which is by far the most important for specific determination. The chelicerae are not known, and only parts of the walking legs are well represented.

Of the four walking legs only one complete limb was found (Text-fig. 2B). The number of joints cannot be determined inasmuch as the joints adjoining the coxa are not distinct. A total of seven or eight joints, however, is indicated. This limb (6003) was found detached, but has been referred to *H. banksii* because of its characteristic ornamentation. It possesses a flattened, elongated coxa, with about fourteen backwardly curved teeth on the gnathobase, decreasing in size posteriorly. The anterior four are rather triangular and grade into very sharp, slender teeth, which become separated from each other by a space equal to twice their width at the base.

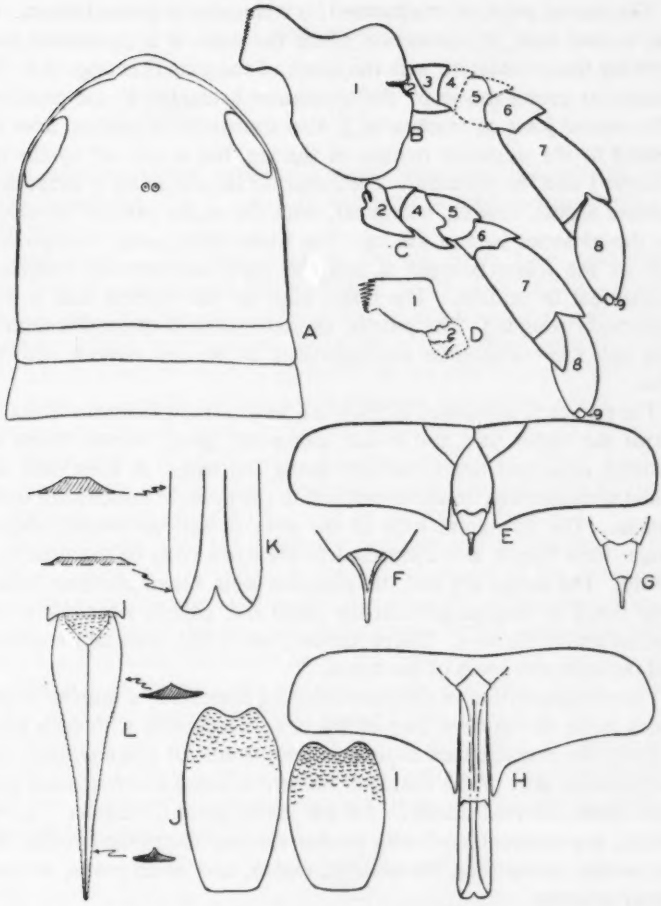
The coxa in Text-fig. 1D apparently belongs to one of the posterior

of the walking legs. This specimen (Zf-2869) is slender, narrow, straight along the anterior edge, and rounded in a gentle curve along the posterior edge. The base shows narrower and longer teeth than those of the coxa of the sixth, or swimming appendage. Each tooth is curved posteriorly and decreases in length backwards; at least nine were present.

At the base of the coxa, on the inner edge, a complete epicoxite was found. This structure is in the form of an elongated or tongue-like body, which articulates with the coxa. The structure is covered by very fine pointed bristles, similar to the smallest teeth on the gnathobase, except that they are smaller. They are crowded along the inner edge and cover the flat face of the epicoxite; none occur along the outer edge except at the distal end (Text-fig. 2B).

The leg tapers gradually from the coxa to the distal end, which is represented by a long spine. These joints progressively decrease in length and are subtubular in general aspect with an uneven ridged surface. The joints appear devoid of any spines except the last two adjoining the terminal spine, which have a long curved spine at their posterior, basal part. Only one spine has been seen on each joint, but from their position it is probable that these occur in pairs, as indicated in Text-fig. 2B. They are slightly curved and longitudinally grooved and are unusually long as compared to other forms of the genus.

The sixth or swimming leg is known from a number of well preserved specimens showing both dorsal and ventral sides. Specimen Zf-2865 includes a complete swimming leg of the right side, in which the coxa is seen from the inside as a mould of the ventral side, the trochanter 1 to the femur (fifth joint) as casts of the dorsal side, the patella (6), tibia (7), tarsus (8), and pretarsus (9), as moulds of the outer surface of the ventral side. Details of the irregular joints from the trochanter 1 to the patella are better known from the ventral aspect. The overall length of the complete leg from the prefemur to the base of the coxa is 50 mm. The coxa, which forms a considerable part of this leg, is 17 mm. from the gnathobase to the point of attachment of the trochanter, and 13 mm. through the central part from anterior to posterior margins. A larger coxa (Zi-3940) measures 19 mm. and 15·2 mm. respectively. The latter is a ventral impression revealing well preserved details of the ornamentation. The main body of the coxa is rounded at both anterior and posterior margins and is connected with the gnathobase by a narrow neck. The teeth of the gnathobase are small, triangular, and directed slightly backwards. Approximately twenty-one teeth are present, progressively decreasing in size posteriorly. In another specimen (89628) only sixteen teeth are developed. The latter is slightly smaller in size and the minute teeth at the posterior end are not developed, although the preservation is excellent in this specimen.



TEXT-FIG. 1.—*Hughmilleria banksii* (Salter), reconstructed from one or more specimens.

A. Prosoma and anterior two tergites.
B. Dorsal side of right swimming leg : impression of coxa taken from ventral side.
C. Ventral side of left swimming leg.
D. Coxa and attached second joint of walking leg.
E. Operculum with female genital appendage, typical form.
F. Distal end of female genital appendage. Triangular area of third segment protrudes outward over the level of the rest of the segment.
G. Variation of second segment of female appendage.
H. Operculum with male genital appendage.
I. Broad type of metastoma.
J. Narrow type of metastoma.
K. Details of distal end of male genital appendage, with cross-sections showing flattened, elevated, median portion.
L. Telson with cross-sections showing median carina.

The second joint, or trochanter 1, is triangular in general aspect. On the ventral side, at midsection along the base, is a prominent knob forming the articulation with the notch of the coxa (Text-fig. 1C). The triangular prolongation of the trochanter 1 reaches to the prefemur. The second joint or trochanter 2, also triangular in outline, does not extend to the posterior margin of the leg, but is cut off by the trochanter 1 and the prefemur. The prefemur (fourth joint) is irregular in general aspect, roughly triangular, with the major portion developed on the posterior part of the leg. The femur (fifth joint) is larger than any of the joints between it and the coxa and appears irregularly trapizoidal in outline. The distal edge on the ventral side is conspicuously rounded. The patella, or sixth joint, is expanded distally, and has short triangular prolongations at the articulation with the tibia.

The paddle is composed of the tibia, tarsus, and pretarsus. The tibia forms the major part and is flat, elongated, gently curved along the anterior edge and nearly straight along the base. A deep cleft was noted at midsection on the dorsal side at the point of attachment to the patella. The triangular lobe of the tibia is well developed, slightly longer than broad, and connected to the main body of the tibia by a suture. The tarsus is a flat, sub-elliptical joint, rather elongate, with a deep notch or emargination at the distal end, slightly posterior to the median line of the joint. The pretarsus is small, flat, unusually rounded, and occupies the notch of the tarsus.

The ornamentation of the swimming leg consists of a number of flat scales along the anterior part of the coxa which join with each other to form the characteristic transverse lines (folds) of *Hughmilleria.* On the posterior part of the coxa are numerous scales and mucrones with their apices directed distally. All the joints, from trochanter 1 to the patella, are ornamentated with similar sparsely distributed scales, but the paddle, comprising the seventh, eighth, and ninth joints, is completely smooth.

The metastoma is represented by several specimens, of which 88907 (see Plate I, Fig. 7) and Zf-2867 are well preserved and undoubtedly represent this species, whereas three rather narrower plates (88908, Zf-2863, Zi-3965) are probably variations of the typical forms but show similar ornamentation. Clarke and Ruedemann (1912, pl. 62, fig. 4) noted comparable variation in the metastomas of *H. socialis* Sarle, and it may represent a sex difference. The typical metastoma is broad, cordate at the anterior margin, broadly rounded laterally, and truncated at the basal margin. The anterior cordate area is deeply emarginate with evenly rounded lobes. The two narrower metastomas have an identical cordate anterior and also have the posterior part truncated. Measurements of the two types are :—

	Length (through centre).	*Greatest Width.*
	mm.	mm.
88907 . .	19·4	14·0
Zf-2863 . .	18·5	10·5
Zf-88908 . .	16·2	10·6
Zi-3965 . .	17·6	10·0

Flat, small semilunar scales of irregular size cover the anterior half of the metastoma (Fig. 1, I and J), whereas the posterior part appears to be smooth.

Opisthosoma.—The mesosoma is known from four specimens (6004 and its counterpart 6004a, 88906, 88909, and Zf-2863) which, although not complete, can be reconstructed with considerable accuracy. In general shape the mesosoma increases to its greatest breadth at the fourth tergite, behind which it gradually tapers into the metasoma. The first tergite is considerably narrower than the remainder, which are all of approximately the same length and have epimeral angles produced into slight horns (Text-fig. 1A). In specimen 88909, where the first two tergites are attached to the prosoma, the first measures 3·5 mm. in length, as compared with 6·0 mm. in the second tergite.

The metasoma joins the mesosoma without any contraction. Contraction, slight as it is, occurs at the second tergite of the metasoma. From the second tergite to the end of the telson the metasoma gradually tapers. The entire opisthosoma therefore has a broad, lanceolate shape, quite like *Hughmilleria socialis* Sarle, the genotype. Each tergite of the metasoma is produced, at the epimeral angles, into short horns : those at the posterior angles of the first tergite of the metasoma (no. 7 of the opisthosoma) are larger than either the preceding or succeeding tergite (Plate I, Figs. 3 and 4). A nearly complete metasoma (88906), with the measurements partly restored, is as follows (width taken at the middle of each tergite) :—

	Length.	*Width.*
	mm.	mm.
1 . .	5·0	21·5
2 . .	5·0	17·2
3 . .	5·1	15·1
4 . .	5·0	12·2
5 . .	5·5	10·2
6 . .	8·2	9·8

These measurements emphasize the gradual tapering of the metasoma as well as the great length of the last tergite of the opisthosoma.

Each tergite of the opisthosoma is ornamented with small subtriangular scales more prominent in the anterior half of each tergite, and in that area the scales gradually widen so that they join to form the raised lines or folds characteristic of *Hughmilleria*. The underside is covered with similar scales.

The telson (Plate I, Figs. 5 and 6) is broad and flattened anteriorly,

gradually tapering to a point, and a median carina runs the entire length on the dorsal side. This carina increases in height backwards, particularly on the posterior fourth of the telson where it rises sharply above the level of the telson and is very likely serrated. When broken this part leaves a narrow groove in the posterior portion of the telson. Ornamentation occurs only at the anterior, where a number of small semi-lunar scales were noted (Text-fig. 1L). The lateral edges are evenly serrated from behind the anterior bulge of the telson.

The female operculum was well preserved in five specimens (6002, 6004, and 6004a (two individuals), and 88914 (also two individuals) ; the male in four (Zf-2861, Zf-2863, Zf-2865, and Zf-2868). The specimens of the female appendage are from the Brodie Collection and undoubtedly were the examples used by Woodward (erroneously referred to *Eurypterus brodiei*).

The opercular plates are slightly concave along the anterior margin and also on the posterior margin. The antero-lateral angles are broadly rounded, whereas the postero-lateral margins are more acute. The inner posterior margins, adjacent to the median appendage, are produced into acute angles which in the male are considerably longer and almost form spurs.

The female appendage (Text-figs. 1E, F, and G ; and Plate II, Figs. 1–3) is spear-shaped in outline and consists of three distinct joints. The main body of the appendage is composed of the first segment truncated at the base where it overlaps the second segment. The second segment forms most of the rest of the appendage and tapers into a deep distal notch where the last, or third, segment joins. The third segment is a spine, wide and flaring at its attachment to the notch of the second segment. The anterior area is raised above the flattened lateral margins (Text-fig. 1F).

Variations in proportion have been noted and in specimen 6002 the second segment is narrower and longer than in other individuals (see Text-fig. 1G). This feature may be explained, as Laurie (1893, p. 513) suggested, by the fact that the appendage was eversible.

Ornamentation comprises fine posteriorly directed semilunar or triangular scales along the anterior part of the plate, increasing in size posteriorly. The triangular areas are covered by very fine scales, as well as the anterior part of the first segment of the mesial appendage. The rest of the appendage is free of ornamentation.

The male operculum is completely known from four specimens. One of these is complete and attached to an individual having most of the mesosoma, metasoma, and swimming legs preserved, whereas the other three specimens were found detached and incomplete, although the preservation of the individual parts is excellent. The triangular areas are but poorly developed in comparison with the female, but the

inner post-lateral ears to the opercular plates are considerably longer than in the female (Text-fig. 1H).

The median appendage is very long and extends to at least the third pair of abdominal plates (Plate II, Figs. 4 and 5). It is approximately seven times as long as broad ; the lateral margins are nearly straight and parallel, terminating in a peculiar, cordate end. The appendage is composed of only two segments, not three as suggested by Størmer (1934, p. 89) in *Hughmilleria norvegica* (Kiaer) (where the preservation was not sufficiently clear to determine the actual number of segments). The anterior or first segment is longer than the second, and the junction occurs slightly below a line connecting the posterior ends of the opercular spurs. The junction appears to be one of overlap, in which the first segment covers the anterior part of the second. Indistinct ridges are reflected on the integument of the first segment, however, not by any means as symmetric or as distinct as the median ridge present on the second segment.

The second segment has a raised ridge along the median part of the segment from the point of attachment with the first segment to the cordate end where the ridge flares outward (Text-fig. 1K), and the sides slope away from this median ridge at a distinct angle. The distal end is deeply emarginate or cordate and flattened in relation to the rest of the segment. In specimen Zf-2868, where only the last segment is preserved, the anterior part was seen to narrow slightly where it is overlapped by the first segment. In longitudinal section the second segment is considerably thicker at the anterior end and flattens toward the cordate distal end (see cross-sections, Text-fig. 1K).

The ornamentation is similar to that of the female operculum. The male mesial appendage, however, is covered on the first segment and on the anterior part of the sloping sides of the second segment with very small, sub-triangular mucrones, directed distally.

Apertures were not discernible on either male or female appendages.

Several young specimens of *Hughmilleria banksii* were found, some of which were nearly complete. Four individuals (2871 and counterpart 2871a, 88908 (two individuals), and 88912) exhibited twelve tergites in the opisthosoma and were therefore farther developed than the various larval stages of other species reported by Clarke and Ruedemann (1912). The opisthosoma of the young forms does not show any appreciable contraction at the second tergite of the metasoma, and has a more gibbous appearance, similar to *Pterygotus* or *Slimonia*. The first tergite was reduced as in the adult stage. The lateral eyes are proportionately larger than in the adult. A nearly complete specimen herein figured (Text-fig. 2A) had an overall length, from the anterior margin of the carapace to the end of the telson, of 18·5 mm. ; greatest breadth, 5·4 mm., occurs at the junction of the third and fourth

tergites. The prosoma is 4·2 mm. in length (estimated, as part of the anterior extremity was not preserved) and 4·8 mm. broad at the base. The lateral eyes measure 2·0 mm. by 0·6 mm. The length of the telson is 4·3 mm. Another specimen, slightly larger but lacking the telson, had an overall length, with the telson estimated, of 22·0 mm., whereas the greatest breadth of the opisthosoma measured 7·0 mm. The prosoma is 4·6 mm. in length, and 6·2 mm. in width at the base. The lateral eye measured 2·0 mm. in length. As previously mentioned, these immature specimens may represent the forms which Woodward (1871, p. 261) recorded as *Eurypterus pygmæus*, a species which the present writer was unable to find in the collections from Perton.

Remarks.

The main specific characteristics of *Hughmilleria banksii* (Salter) are :

(1) The prolongation of the prosoma into a slightly bent but conspicuous protuberance at the anterior margin.
(2) Details of the swimming leg.
(3) Details of the male and female median appendages.
(4) Details of the serrated telson.

In comparison with other forms, *H. banksii* resembles the genotype *H. socialis* Sarle, but differs in the characteristic protuberance of the prosoma and in details of the swimming leg and the male and female median appendages. The telson of *H. socialis* is proportionately much shorter and more expanded. The form known as *Hughmilleria socialis* var. *robusta* Sarle should be included under the genotype as it is, in this writer's opinion, only a more advanced growth stage.

Hughmilleria lanceolata (Salter) differs in the position of the marginal eyes as well as the characteristics enumerated above and the same differences serve to separate *H. norvegica* (Kiaer).

H. banksii is probably a good index fossil for the Downtonian in southern England. All specimens which have been figured are restricted to the Downtonian of Herefordshire.

Genus SALTEROPTERUS Kjellesvig-Waering n. gen.

Diagnosis.—Anterior part of telson broadly trigonal, serrated on the posterior edges and followed by a long, flat median stem, which expands into a flattened trilobed posterior end. Telson carinated on the dorsal side except at the posterior trilobed structure. Ornamentation of pointed, triangular mucrones on the opisthosoma.

Genotype : *Eurypterus abbreviatus* Salter (1859, p. 234, fig. 18).

In 1859 (p. 234) Salter described and figured a single small telson under the name *Eurypterus abbreviatus* from the Downtonian sandstone of Kington, Herefordshire. Later Woodward (1871, p. 261) reported another individual under the same name in specimens collected by the

Rev. P. B. Brodie from the lower Downtonian at Perton, Herefordshire. There is little doubt that Woodward's specimen is 88911, and its counterpart 5998, which are used in the present description.

Both Salter's and Woodward's specimens are not complete, and merely show the anterior part of the telson. A specimen (Zf-2864) collected by R. W. Pocock and A. J. Butler in 1939 at Perton Quarry includes the entire telson with fragments of the posterior tergites of the metasoma, and this specimen reveals the surprising features which distinguish this from all other known Eurypterida. Normally a genus is rarely described on the basis of the telson ; but, as in the case of *Hastimima*, *Salteropterus* is so distinctly different that comparison with other genera is superfluous.

The complete telson is comprised of a flat trigonal anterior part followed by a long stem which expands into a narrow trilobed organ, and this " supplementary telson ", if such a term can be used, is an entirely new feature. In general aspect the trilobed part resembles the cauda of some crustacea except that the three lobes in *Salteropterus* are reversed, with the central lobe under the two side lobes. No segmentation has been observed and the lobes were probably immovable. Suggestion of possible segmentation is seen in the lower part of the stem joining the " supplementary telson ", with thin partings, spaced as one would expect if the stem were segmented. However, it is more probable that these partings are cracks in the fragile and narrow stem, as segmentation of the telson is a feature entirely unknown in any of the Eurypterida. That the lower part of the telson must have been rather flexible is suggested by the bent nature of the stem in the complete telson (Zf-2864) and in the incomplete telson (5998) in which the stem, although broken, is bent to the right at an angle. It is suggested that the " supplementary telson " had a balancing function additional to the large and flaring telson.

Slimonia appears to resemble *Salteropterus* in general and in our present knowledge is the genus most closely allied. The broad telson with its long terminal spine as well as the tapering and rather long posterior metasomatic tergites bear a superficial resemblance to *Salteropterus*. The ornamentation of *Salteropterus* is characteristic of the *Hughmilleriidae* and not of *Pterygotidae*.

Salteropterus abbreviatus (Salter)

Plate II, Figs. 6, 7 ; Text-fig. 2D, E, F, G, H,

Eurypterus abbreviatus Salter, 1859b, p. 234, pl. x, fig. 18.
Eurypterus abbreviatus Bigsby, 1859, p. 321.
Eurypterus abbreviatus Woodward, 1864, p. 107.
Eurypterus abbreviatus Woodward, 1871b, p. 261.
Eurypterus abbreviatus Woodward, 1872 (1866–1878), p. 148, pl. xxvii, fig. 14.
Eurypterus abbreviatus Woodward, 1877, p. 64.

Eurypterus abbreviatus Etheridge, 1888, p. 52.
Eurypterus abbreviatus O'Connell, 1916, p. 38.
Eurypterus abbreviatus Diener, 1924, p. 15.
Eurypterus abbreviatus King, 1934, p. 563.

The species is known mainly by the telson, which is trigonal in general aspect at the anterior end and possesses a long stem-like structure which expands into an elongated, three-lobed organ (Text-fig. 2D). The anterior part of the telson is flat, thickest at the truncated base adjoining the metasoma. The lateral margins flare outward to reach their greatest width at the post-lateral angles, where they abruptly turn inward and narrow into the long stem-like structure. The post-lateral areas on each side are slightly bent downward. The dorsal side has a very slight carina through the median line which increases in height on the stem (Text-fig. 2E).

The posterior half of the anterior region is bounded by sharp, flat scales, forming a conspicuous serrated edge, which increase in size at the post-lateral angles. These scales become less pointed but more rounded at the posterior edges, and finally grade ventrally into conspicuous knob-like protuberances or coarse pustules.

The long stem-like structure in specimen Zf-2864 (Plate II, Fig. 6) measures 2·5 mm. at its junction with the trigonal area, and narrows to 0·8 mm. immediately before expansion into the trilobed posterior end. Each side of the stem is ornamented on the ventral side with tubercles arranged in pairs along the length of the stem. These knobs gradually flatten towards the lower third of the stem, where they are less conspicuous. In this region indistinct partings separate the stem into what may be segments, but these are probably due to cracks across the integument. The narrowness here implies some degree of flexibility.

The dorsal side of the stem has been seen only in a small fragment from the anterior end (specimen 88911, Plate II, Fig. 7). The carina of the trigonal area continues down the stem, at least on the anterior end, as a blunt central carina, more prominent than that of the trigonal area. No tubercles were observed on the dorsal side.

The curious terminal structure is comprised of three distinct elongated lobes. The central lobe extends beyond the side lobes and occupies a ventral position (Plate II, Fig. 6 ; Text-figs. 2D, F, G).

The complete telson (Zf-2864) measures 31·3 mm. in length, of which approximately 8·8 mm. represents the length of the trigonal area, 13 mm. the stem, and 9·5 mm. the length of the posterior trilobed area. Width of the trigonal area is 13 mm. The specimen used by Woodward (1864, p. 107) is slightly larger, measuring 16·5 mm. in greatest width. A reconstruction of the telson, based almost entirely on the complete specimen (Zf-2864) is given in Text-fig. 2D.

Only fragments of the last three tergites of the metasoma are known.

These are tapering, very elongated, and resemble in general the distal tergites of the metasoma of *Slimonia*.

A small patch of a mesosomatic tergite (Zf-2866) reveals large, raised, triangular mucrones, the largest of which (4 mm. in breadth) suggests that *S. abbreviatus* reached considerable proportions (Text-fig. 2H).

Family PTERYGOTIDAE Clarke and Ruedemann

Genus PTERYGOTUS Agassiz 1839

Pterygotus (*Erettopterus*) *gigas* Salter

Pl. III, Fig. 2

Pterygotus problematicus Banks, 1856, p. 93, etc.
Pterygotus (*Pterygotus*) *gigas* Salter, 1859a, p. 83, pls. viii and ix.
Pterygotus gigas Bigsby, 1859, p. 322.
Pterygotus gigas Woodward, 1872 (1866–1878), pp. 79–85, text-figs. 17, 18.
Pterygotus gigas Salter, 1873, p. 189.
Pterygotus gigas Woodward, 1877, p. 67.
Pterygotus gigas Schmidt, 1883, p. 29.
Pterygotus gigas Etheridge, 1888, p. 66.
Pterygotus gigas Semper, 1898, p. 75.
Pterygotus gigas Seemann, 1906, p. 56.
Pterygotus gigas O'Connell, 1916, p. 45.
Pterygotus gigas Diener, 1924, p. 12.
Pterygotus gigas Størmer, 1934b, p. 95.
Pterygotus gigas King, 1934, p. 563.
Pterygotus (*Erettopterus* ?) *gigas* Størmer, 1936, p. 41.

Of several fragments indicating a large *Pterygotus*, only one nearly complete metastoma can be properly referred to *Pterygotus gigas* Salter. The other fragments (small parts of large tergites, and a gnathobase) cannot be specifically determined.

The metastoma (Zf-2862) figured on Plate III, Fig. 2, is preserved in sandstone without any trace of ornamentation. The metastoma is cordate at the anterior end, being evenly rounded at the two lobes with a deep emargination at the middle. The margins are slightly curved inward to give the plate a rather elongated aspect. The base is not complete. The greatest width occurs at the anterior half. In length this metastoma measures 29·2 mm. through the centre, 31 mm. in greatest length, and 19·4 mm. in greatest breadth.

Family EURYPTERIDAE Burmeister

Genus EURYPTERUS Dekay 1825

Eurypterus brodiei H. Woodward

Pl. III, Fig. 1 ; Text-fig. 2I

Eurypterus brodiei Woodward, 1870, p. 91.
Eurypterus brodiei Woodward, 1871b, pp. 261–3, fig. 1 (not 2, 3).
Eurypterus brodiei Woodward, 1871a, p. 276.
Eurypterus brodiei Woodward, 1872 (1866–1878), pp. 161–3, fig. 53 (1) (not 2, 3).

Eurypterus brodiei Woodward, 1877, p. 64.
Eurypterus brodiei Etheridge, 1888, p. 52.
Eurypterus brodiei Woodward, 1907, p. 278.
Eurypterus brodiei O'Connell, 1916, p. 39.
Eurypterus brodiei Diener, 1924, p. 16.
Eurypterus brodiei Størmer, 1934b, p. 19.
Eurypterus brodiei King, 1934, p. 563.
Eurypterus brodiei Størmer, 1936, p. 33.
Not *Eurypterus brodiei* Woodward, 1871b, pp. 262–3 (in part), figs. 2–3 (see *Hughmilleria banksii*).
Not *Eurypterus brodiei* Woodward, 1872 (1866–1878), pp. 162–3 (in part), fig. 51 (2, 3) (see *Hughmilleria banksii*).

The original description and figures of *Eurypterus brodiei* Woodward (1871b, p. 261, figs. 1–3) are composite, including *Hughmilleria banksii* and a definite *Eurypterus*. The holotype (B.M.N.H. I 3033) is fortunately a *Eurypterus* and the species *E. brodiei* is therefore valid. The holotype comprises a nearly complete form, preserved as a dorsal impression, but lacking entirely all the prosomal appendages except part of the right swimming leg. Woodward, in his figs. 1 and 2, uses this specimen as a basis but erroneously adds walking legs which undoubtedly belong to another form, possibly *Hughmilleria banksii*.

The operculum which Woodward illustrated in Fig. 3 is properly the female operculum of *Hughmilleria banksii*, and this structure remains unknown in *Eurypterus brodiei*.

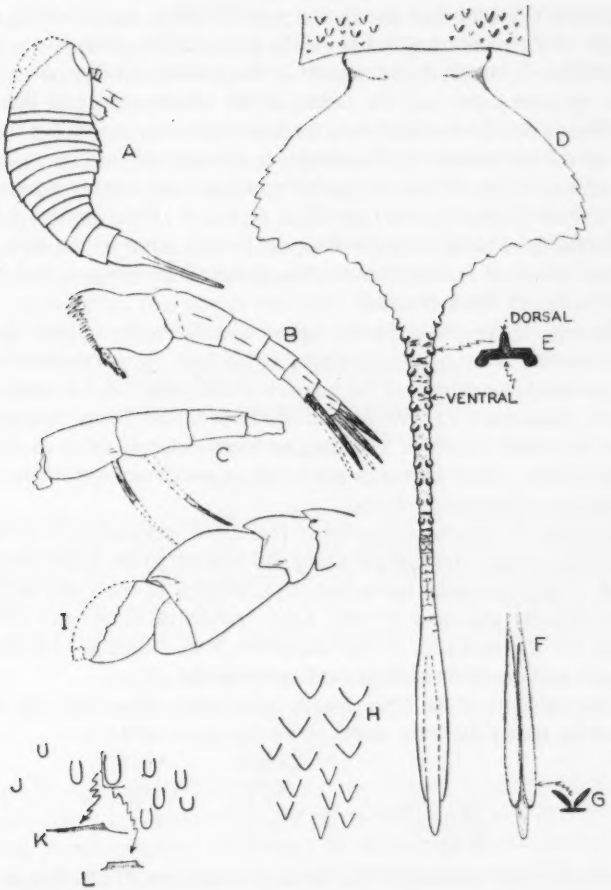
Eurypterus brodiei is a rare species in the Downtonian of Perton. The description which follows is based on an excellent plaster cast of the holotype, and on photographs. Other than the holotype the material studied comprises only small fragments which include the swimming leg and are of considerable diagnostic value in the differentiation of *Eurypterus*.

Prosoma.—The holotype has part of the dorsal surface of the prosoma removed, although the outlines of the shield are preserved. The specimen has suffered compression and the lateral eyes and ocelli are indistinct.

The general shape is subquadrate in outline, rounded at the antero-lateral margins, and bounded by a narrow marginal rim. The base is straight. Lateral eyes are indistinguishable on the plaster cast, but were probably subcentral as indicated by Woodward. The ocelli are missing but probably occupied a position posterior to the lateral eyes, as in other species of the genus, and not anterior to the eyes as Woodward indicated in his original figure.

The prosoma (crushed) measures 12·5 mm. in length and 20·5 mm. in width at the base, giving a length–width ratio of 6·1 : 10. Very likely uncrushed specimens would be narrower.

The underside of the prosoma is unknown except for details of part of the sixth appendage or swimming leg. Besides the holotype, two



TEXT-FIG. 2.—

A. Young specimen of *Hughmilleria banksii* (Salter). Overall length is 18·5 mm. Zf-2871 and Zf-2871a.
B. Walking leg with attached epicoxite of *Hughmilleria banksii* (Salter) 6003.
C. *Mixopterus* sp. Fragment of a walking leg; probably the third appendage. 88910.
D. Reconstruction of the ventral side of the telson of *Salteropterus abbreviatus* (Salter).
E. Cross-section through stem of the telson of *Salteropterus abbreviatus* (Salter) to show the median carina on the dorsal side and paired knobs of the ventral side.
F. Reconstruction of the dorsal side of the trilobed structure at the posterior end of the telson of *Salteropterus abbreviatus* (Salter).
G. Cross-section through the trilobed part of the telson of *Salteropterus abbreviatus* (Salter).
H. Ornamentation of the integument of *Salteropterus abbreviatus* (Salter) based on specimen Zf-2866. The largest of the triangular mucrones measures 4 mm. in breadth.
I. Reconstruction of the distal joints of the swimming leg of *Eurypterus brodiei* (Woodward) based on specimens Zf-2868, Zf-2868a, and Zi-3932.
J, K. L. Nature of the ornamentation of *Carcinosoma* sp., based on specimen Zi-3955.

All from the lower Downtonian at Perton, Herefordshire, in the collections of the Geological Survey and Museum.

specimens (Zf-2868 and its counterpart Zf-2868a, and Zi-3932) reveal details of the swimming leg from the femur (fifth joint) to the tarsus (eighth joint), which includes most of the paddle. Comparisons of the tibia (seventh joint) and the tarsus of the swimming leg in the genus *Eurypterus* should be made only in cases where specimens are more or less of the same size. For example, in *Eurypterus remipes*, immature specimens about 40 mm. in length reveal a considerably longer tibia and a much greater tarsus than adult forms. In these immature forms the tarsus is as large or larger than the area covered by the tibia. The reverse is true of mature forms. The change is progressive and dependent on age of the individual.

The type of *Eurypterus brodiei* has an overall length of about 62 mm., and therefore is not a fully developed individual. As a consequence, the tibia is more elongated and the tarsus is much larger than in more adult forms. Specimens Zf-2868 and Zi-3932 are larger, being estimated to have an overall length of 130 mm., or approximately twice as large as the holotype. These estimates are based on numerous specimens of the well-known *Eurypterus remipes*.

The tibia of *Eurypterus brodiei* in the larger specimens (Zf-2868 and Zi-3932) is broad and straight along the base up to the triangular lobe, which is large, broadly triangular, and rounded at the outer edge. In most respects the tibia of this form resembles *Eurypterus remipes*, except for the structure of the triangular lobe, which is considerably broader and curves inward at the base (Text-fig. 2I).

Measurements of the tibia (length being taken along the base to the end of the triangular lobe, width being the maximum) :—

	Length. mm.	*Width.* mm.
Holotype .	8·4	6·0
Zf-2868a . .	16·0	9·5
Zi-3932 . .	15·5	9·5

Among larger specimens the tarsus is found on Zf-2868a and only approximately half of the structure is preserved. The outline suggests a broad, sub-elliptical form, broader than that of the holotype. The latter has not been measured, as the cast does not show sufficient detail.

Mesosoma.—The tergites of the mesosoma are not as clearly defined as on the metasoma. The first tergite appears to be narrower than the succeeding. The greatest breadth occurs at the posterior part of the third tergite attaining 22·3 mm.

Metasoma.—The first tergite has slight horns produced at the epimera, with contraction of the metastoma occurring at the second tergite. All the tergites taper, but inasmuch as the edges are covered the tapering is probably not as great as shown on the holotype. Length measurements are possible as little telescoping of the segments occurs. Width measurements are impossible as a result of partial concealment.

Average: Tergite 1, 3·5 mm.; tergite 2, 3·6 mm.; tergite 3, 4·0 mm.; tergite 4, 4·0 mm.; tergite 5, 4·2 mm.; tergite 6, 5·1 mm. The telson is spike-like, measures 10·4 mm. in length and 2·1 mm. in width at its junction with the last tergite.

Remarks.—Compared with the American *Eurypterus remipes* Dekay and *Eurypterus lacustris* Harlan, the main differences are found in the swimming leg. The structure of the triangular lobe of the tibia in *Eurypterus brodiei* Woodward is sufficient to separate it from the common American forms. From *Eurypterus fischeri* Eichwald, *E. brodiei* likewise differs in the structures of the swimming leg: *E. fischeri* has a much broader tibia and tarsus and also does not have the incurving triangular lobe.

Family CARCINOSOMIDAE Størmer

Genus CARCINOSOMA Claypole 1890

Carcinosoma sp.

Text-fig. 2J, K, L

A single fragmentary specimen (Zi-3955), possibly a tergite, indicates the presence of a *Carcinosoma*. The ornamentation of raised, elongated, semi-elliptical, scale-like sculpture is not unlike that of *Carcinosoma punctatus* (Salter, 1859a, Pl. XIII, Figs. 5, 5a). The fragment from Perton, however, can only be generically identified (Text-fig. 2J, K, L).

Genus MIXOPTERUS Ruedemann 1921

Mixopterus sp.

Text-fig. 2C

A small fragment (88910) having an overall length of 20 mm., represents parts of five joints of the third appendage of a *Mixopterus*, probably comprising the major part of the second to the sixth joints (Text-fig. 2C). These joints taper toward the distal end and are devoid of any ornamentation. Although the leg was originally spinous, only two fragmentary spines were found, one at the base of a joint, the other placed nearly in the middle of another joint. Both spines are very long and grooved with fine striations.

The fragment found is too incomplete for detailed comparison with other species of the genus *Mixopterus*. The only British *Mixopterus* known is *M. dolichoschelus* (Laurie), a form which bears only slight resemblance to the above fragment. The genotype, *M. multispinosus* (Clarke and Ruedemann), however, does bear a marked resemblance, but the quality of the material available is unsufficient for a closer comparison. It is of interest to note, nevertheless, the similar association of various Eurypterid genera in both the Pittsford of New York and the Downtonian of Perton.

Family STYLONURIDAE Diener

Genus TARSOPTERUS Clarke and Ruedemann 1912

Tarsopterus (?) sp.

Pl. III, Figs. 3 and 4

A single specimen (Zf-2872 and Zf-2872a), comprising a fragment of the coxa and attached second joint of the sixth appendage, is doubtfully referred to the genus *Tarsopterus*. It is of considerable interest inasmuch as Størmer found a fragment, which apparently represents the same genus, in the fish horizon of the Downtonian sandstone of Rudstangen, Ringerike, Norway. Størmer's specimen (1934, p. 116, pl. 12, fig. 2) comprises two joints of a leg, and except for the teeth-like development along the margins of the joints resembles the specimen herein described.

The joint from Perton (Pl. III, Figs. 3 and 4) suggests a rather robust eurypterid, possibly exceeding 30 cm. in overall length. The joint, which is nearly complete, measures 22 mm. in length and 13·5 mm. in greatest breadth. The ornamentation is particularly striking, consisting of rounded tubercles or wart-like structures of uneven size, some of which occur in indefinite rows. The fragmentary coxa is devoid of ornamentation, but is important as proving that the fragments represent an unusual eurypterid. Størmer (1934, p. 116) previously suggested that his fragment might belong to another arthropod group other than the Eurypterida.

The ornamentation suggests one of the Stylonuridae, although it is not impossible that the fragments are parts of *Salteropterus abbreviatus*, as the telson of the latter has a development of knobs not unlike those found on the peculiar joint described above. It is certain that we are dealing with a rare and very unusual eurypterid, which differs greatly from any yet described.

REFERENCES

BANKS, W. R., 1856. On the Tilestones or Downton Sandstones in the Neighbourhood of Kington and their Contents. *Quart. Journ. Geol. Soc.*, xii, 93–102.

BIGSBY, J. J., 1859. An inquiry into the Sedimentary and other External Relations of the Palaeozoic Fossils of the State of New York. *Ibid.*, xv, 251-335.

BRODIE, P. B., 1869. On the Occurrence of *Eurypterus* and *Pterygotus* in the Upper Silurian Rocks of Herefordshire. *Ibid.*, xxv, 235–7.

—— 1871. On the " Passage-beds " in the neighbourhood of Woolhope . . . *Geol. Mag.*, viii, 230.

CLARKE, J. M., and RUEDEMANN, R., 1912. The Eurypterida of New York. *New York State Mus. Mem.* 14.

DIENER, C., 1924. *Fossilium Catalogus*, I, *Animalia*. Pars 25 : Eurypterida, Berlin.

ELLES, G. L., and SLATER, I. L., 1906. The Highest Silurian Rocks of the Ludlow District. *Quart. Journ. Geol. Soc.*, lxii, 195–222.

ETHERIDGE, R., 1888. *Fossils of the British Islands stratigraphically and zoologically arranged*, 1, Palaeozoic.
KING., W. W., 1934. The Downtonian and Dittonian strata of Great Britain and North-Western Europe. *Quart. Journ. Geol. Soc.*, xc, 526–566.
KJELLESVIG-WAERING, E. N., 1950. A new Silurian *Hughmilleria* from West Virginia. *Journ. Pal.*, 24, 226–8.
LAURIE, M., 1893. The Anatomy and Relations of the Eurypteridae. *Trans. Roy. Soc. Edin.*, 37, 509–528 (1895).
O'CONNELL, M., 1916. The Habitat of the Eurypterida. *Bull. Buffalo Soc. Nat. Sci.*, xi, 277.
SALTER, J. W., 1856a. On some new Crustacea from the Uppermost Silurian Rocks. *Quart. Journ. Geol. Soc.*, xii, 26–34.
—— 1856b. *In* Murchison's *Siluria* (2nd ed.).
—— 1859a. On the Anatomy and Affinities of the Genus *Pterygotus* and Description of New Species of *Pterygotus*. *Mem. Geol. Surv. United Kingdom, Monograph I*, pt. ii, 37–105.
—— 1859b. On some New Species of *Eurypterus*; with notes on the Distribution of Species. *Quart. Journ. Geol. Soc.*, xv, 232–6.
—— 1859c. *In* Murchison's *Siluria* (3rd ed.).
—— 1867. Op. cit (4th ed.).
—— 1873. *Catalogue of Cambrian and Silurian Fossils in the Woodwardian Museum*, Cambridge.
SARLE, C. J., 1903. A new Eurypterid Fauna from the Base of the Salina of Western New York. *New York State Mus. Bull.* 69, 1080–1108.
SCHMIDT, F., 1883. Die Crustaceen-fauna der Eurypteren-schichten von Rootzikull auf Oesel. *Mém. Acad. imp. Sci., St. Petersb.*, ser. 7, xxxi, 28–88.
SEEMANN, F., 1906. Beiträge zur Gigantostrakenfauna Böhmens. *Beitr. Paläont. Östrr.-Ung.*, xix, 49–57.
SEMPER, M., 1898. Die Gigantostraken des älteren bohmischen Pälaozoicum. *Ibid.*, ii, 71–88.
STØRMER, L., 1934a. A new eurypterid from the Saaremaa- (Oesel-) beds in Estonia. *Tartu Univ., Geol. Inst., Pub.*, 244–250.
—— 1934b. Merostomata from the Downtonian Sandstone of Ringerike, Norway. *Skrifter Norske Vidensk.-Akad. Oslo*, I Mat.-Naturv. Klasse, 1933, no. 10.
—— 1936. Eurypteriden aus dem rheinischen Unterdevon. *Preuss. Geol. Landesanst.*, Anh. N.F., H. 175.
WOODWARD, H., 1864. On a Nearly Perfect Specimen of *Eurypterus lanceolatus* (Salter) from the Upper Ludlow Rock at Lesmahagow, Lanarkshire. *Geol. Mag.*, 1, 107–114.
—— 1866–1878. A Monograph of the British Fossil Crustacea belonging to the order Merostomata. *Palaeontographical Soc.*, London.
—— 1870. *Rept. British Assoc.* (Liverpool), Section C, 91.
—— 1871a. *Trans. Woolhope Field Naturalist's Club.*
—— 1871b. On a New Species of *Eurypterus* (*E. Brodiei*) from Perton, near Stoke Edith, Herefordshire. *Quart. Journ. Geol. Soc.*, xxvii, 261–3.
—— 1877. Catalogue of the British Fossil Crustacea with their Synonyms and the Range in Time of each Genus and Order. *British Mus. Nat. Hist.*
—— 1907. Two new *Eurypterus* from the Coal Measures of Ilkeston, Derbyshire. *Geol. Mag.*, xliv, 277–282.

EXPLANATION OF PLATES I–III

PLATE I

FIG. 1.—*Hughmilleria banksii* (Salter). Nearly complete prosoma and attached first two tergites of the mesosoma. The former retains the original outlines and is considered typical for the species. Part of the

swimming leg (fifth to seventh joints) of *Eurypterus brodiei* covers the right lateral eye. 88909. × 1·6.

FIG. 2.—*Hughmilleria banksii* (Salter). Crushed prosoma and attached first tergite, showing the diagnostic anterior protuberance. 2866. × 1·5.

FIG. 3.—*Hughmilleria banksii* (Salter). Complete metasoma with part of the posterior part of the mesosoma and the anterior part of the telson in dorsal aspect. Note spur of the first tergite of the metasoma on the right side. 6004. × 1·5.

FIG. 4.—*Hughmilleria banksii* (Salter). Complete metasoma and anterior part of the telson in dorsal aspect, showing spur of the first tergite of the metasoma, as well as the normal constriction of the metasoma. 88906. × 1·5.

FIG. 5.—*Hughmilleria banksii* (Salter). Dorsal side of complete telson, showing fine serrations on the lateral margins. 88909. × 1·7.

FIG. 6.—*Hughmilleria banksii* (Salter). Dorsal side of complete telson, showing the slight median carina and groove in the posterior end, where the carina has been broken off. 88907. × 1·7.

FIG. 7.—*Hughmilleria banksii* (Salter). Complete metastoma of the broader type. See Text-fig. 1I and J. 88907. × 1·6.

All from the lower Downtonian shales at Perton, Herefordshire, in the collections of the Geological Survey and Museum.

PLATE II

FIGS. 1 and 2.—*Hughmilleria banksii* (Salter). Complete female operculum and median appendage. The spine-like distal segment of the median appendage is well preserved and entire. Fig. 1 represents the counterpart. 6004 and 6004a. × 1·5.

FIG. 3.—*Hughmilleria banksii* (Salter). Female operculum and median appendage. This specimen is larger than that figured above, and has a considerably stouter distal segment of the median appendage. 88914. × 1·6.

FIG. 4.—*Hughmilleria banksii* (Salter). Male operculum and broken median appendage. Horns of the opercular plates are covered. Zf-2865. × 1·5.

FIG. 5.—*Hughmilleria banksii* (Salter). Incomplete male operculum and complete median appendage. Horns of the opercular plates are partly covered. Zf-2863. × 1·3.

FIG. 6.—*Salteropterus abbreviatus* (Salter). Specimen showing the ventral side of the last three tergites of the metasoma, with attached complete telson, and the unusual, long stem with narrow trilobed distal end. Zf-2864. × 2·2.

FIG. 7.—*Salteropterus abbreviatus* (Salter). The anterior trigonal area of the telson. The long stem and distal-trilobed part have been broken away. 5998. × 1·8.

All from the lower Downtonian shales at Perton, Herefordshire, in the collections of the Geological Survey and Museum.

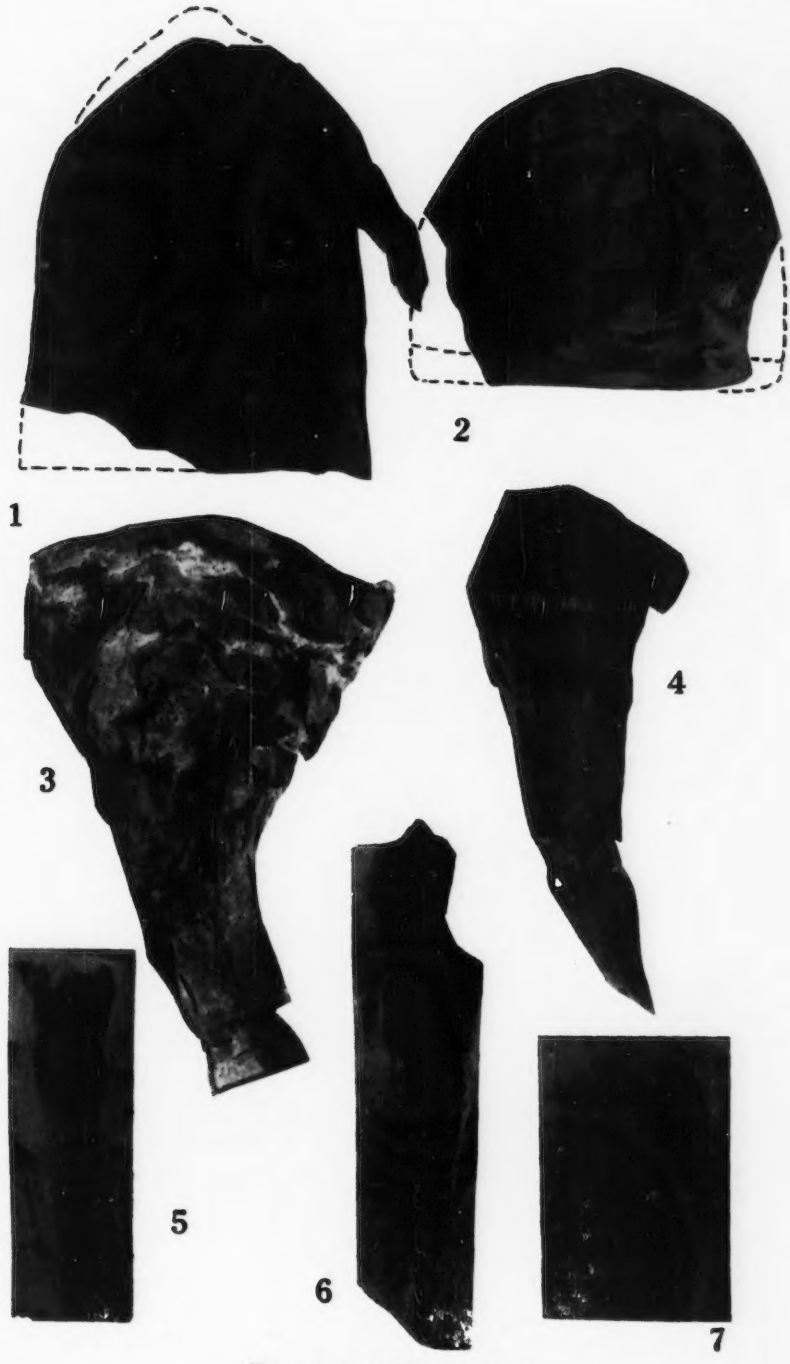
PLATE III

FIG. 1.—*Eurypterus brodiei* Woodward. The holotype of the species. The photograph was made by the British Museum (Natural History); outlines in ink by the writer from plaster casts. The outlines of the prosoma have been superimposed from the relievo. I. 3033 (B.M.N.H.) × 2.

FIG. 2.—*Pterygotus gigas* Salter. Nearly complete metastoma. 2862. × 1·6.

FIGS. 3 and 4.—*Tarsopterus* (?) sp. Incomplete coxa and attached joint of a peculiar form and counterpart. Zf-2872 and Zf-2872a. × 1·5.

All from the lower Downtonian at Perton, Herefordshire, and, with the exception of Fig. 1, in the collections of the Geological Survey and Museum.



DOWNTONIAN EURYPTERIDA.

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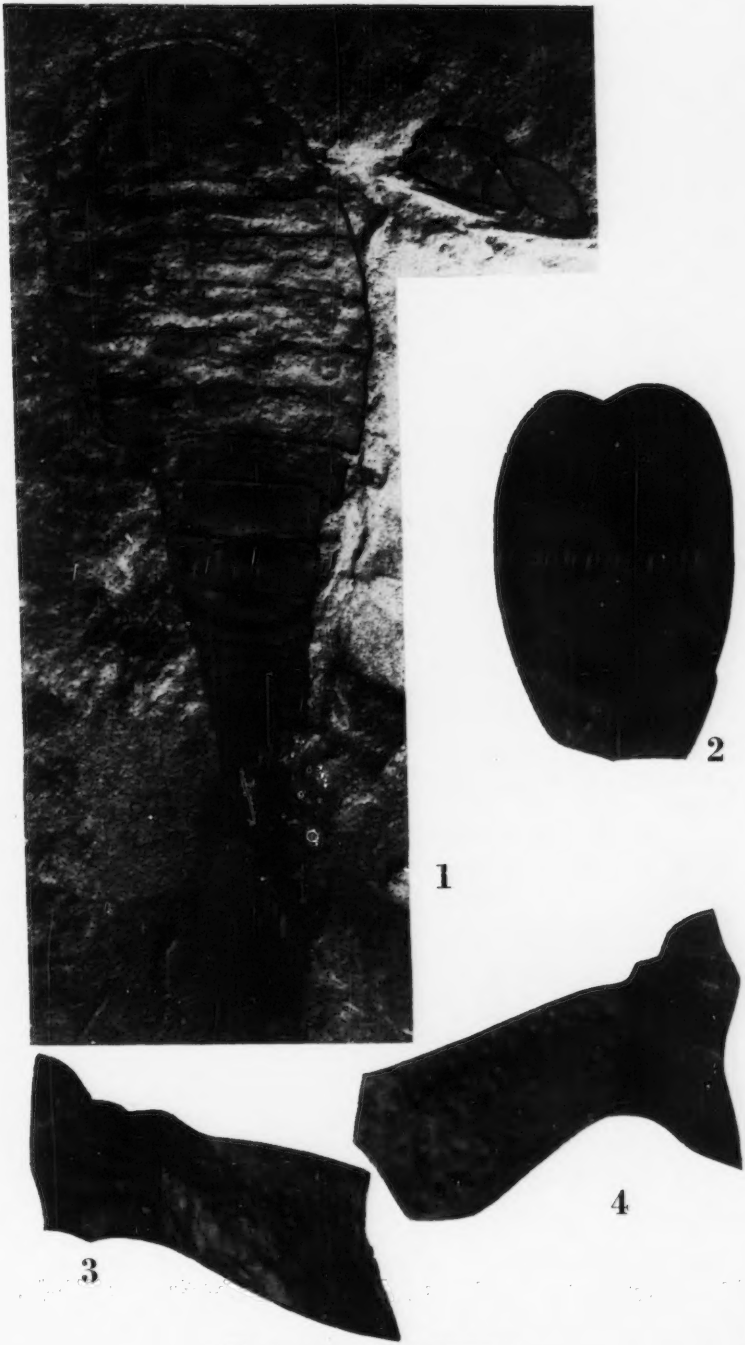
DOWNTONIAN EURYPTERIDA.



DOWNTONIAN EURYPTERIDA.

Varying Trends in the Metamorphism of Dolerites

By JOHN SUTTON and JANET WATSON

ABSTRACT

The metamorphism of Pre-Cambrian dolerites in the Northwest Highlands is described and compared with that of basic rocks in the Southwest Highlands, Banffshire and other regions. The first products of metamorphism are not the same in every area. It is suggested that the trend of regional metamorphism differs according to the environment in which it took place, and that a sequence of changes established in one area cannot be used as a standard by which to judge the changes in other areas. In particular, rocks of high metamorphic grade have not invariably passed through stages characterized by low-grade minerals.

INTRODUCTION

THE accumulation of sediments in a geosynclinal trough is often accompanied by the rise of basic magma into the geosyncline. This magma may be ejected as lava flows or may consolidate below the earth's surface in the form of doleritic dykes and sills. The derivatives of these rocks are of frequent occurrence in regionally metamorphosed orogenic belts and have been described from many parts of the world. Comparison of the progressive metamorphism of dolerites from various localities shows that a number of apparent anomalies exist, and that the sequence of changes is not the same in every case. The purpose of the present paper is to consider the implications of this variation in the trend of metamorphism.

The study is confined to basic rocks which form dykes and sills, and which have a doleritic texture. Such rocks are particularly suitable subjects for the investigation of progressive metamorphism. They react readily to relatively slight changes in their environment, and a number of distinctive index minerals become available. But the most important character of the dolerites from this point of view, and the one in which they differ from the associated sedimentary rocks undergoing metamorphism, is the presence of a clearly-defined original texture and a set of known original minerals. In the early stages of metamorphism, remnants of these minerals may be preserved and the original texture may still be recognizable, so that the very first products of metamorphism can be identified. The chief cause of uncertainty is the variation in the extent to which autometamorphic changes took place immediately after the solidification of the rock. If these changes have been great, the original magmatic minerals will have been destroyed before the onset of regional metamorphism. With this limitation, however, the dolerites provide very accurate information as to the earliest stages of metamorphism.

One of the most complete accounts of the metamorphism of doleritic

rocks is the description by Wiseman (1934) of the epidiorites of the Southwest Highlands. In these rocks, the first formed minerals are albite, chlorite, epidote, and hornblende. Wiseman regarded the epidiorites of Banff and Aberdeenshire, which had previously been described by Read (1923), as abnormal, in that albite, epidote, and chlorite are absent and the minerals first formed are andesine and hornblende. In the Northwest Highlands of Scotland, however, this " abnormal " metamorphic sequence is found to be typical of a very wide area. In this paper a detailed description of the metamorphism of the Northwest Highland dolerites is given and it is followed by a general discussion of the trends of metamorphism in dolerites.

Throughout the paper, the term " metadolerite " has been used to signify a dolerite that has been metamorphosed. The name has a wider application than the word " epidiorite " to which a definite mineralogical significance is usually attached.

Laxfordian Metamorphism of Dolerites in the Northwest Highlands

The series of dolerite dykes of the Northwest Highlands has been described by Teall and others (1885, 1907). Recent work has shown that the dykes were intruded into an Archaean metamorphic complex (the Scourian Complex), and that they underwent regional metamorphism during a later Pre-Torridonian epoch which has been called the Laxfordian period.

The dykes have a N.W.–S.E. trend and are nearly vertical. They range in thickness from a few inches up to fifty yards. The smaller dykes are fine-grained throughout, and wider dykes have chilled edges and a coarser central part in which the felspars may be half a centimetre long.

The dyke series is fairly constant in original composition, the chief variations being due to the presence or absence of hypersthene and olivine. A plagioclase, labradorite, or andesine, and augite are the most abundant minerals. Orthorhombic pyroxene is often present, but is always subordinate to the augite. Olivine is relatively rare. Ilmenite, magnetite, and apatite occur as accessory minerals. The texture of the rock is subophitic. The lath-like felspars have a random orientation and form a framework which is filled in by the granular mafic minerals. The interstitial spaces are often occupied by irregular patches of more acid felspar. The large felspar laths tend to be aggregated in clots, and the rock has therefore a mottled appearance in hand specimen.

In the parts of the Northwest Highlands which lie to the north of Scourie, and to the south of Gruinard Bay, the dolerites and the

gneisses which they intrude have been metamorphosed during the Laxfordian period. The general nature and effect of this metamorphic episode have been discussed in a recent paper and the description that follows here is confined to the behaviour of the dykes themselves. During the Laxfordian period, metamorphism and deformation took place simultaneously and the dolerites show traces of both operations.

The course of metamorphism is remarkably similar in all the areas affected by the Laxfordian metamorphism. The material on which the following description is based is taken from the regions of Loch Torridon and Loch Laxford.

The process of metamorphism of the dykes can be divided into six stages marked by the following events :—

(1) Development of secondary hornblende around pyroxene grains, without destruction of the original texture.

(2) Replacement of pyroxene by quartz-hornblende aggregates, without destruction of the original texture.

(3) Recrystallization of the felspar laths with partial modification of the original texture.

(4) Recrystallization of the quartz-hornblende aggregates with complete destruction of the original texture.

(5) Appearance of biotite.

(6) Development of green augite.

The sixth stage is found only in the Loch Laxford area.

Metamorphism is accompanied by metasomatism in the Laxfordian period, and metadolerites in stages 4, 5, and 6 frequently show signs of migmatization. It is no part of the object of this paper to describe the changes that the dykes undergo during migmatization, and the later stages of metamorphism are therefore omitted from the following descriptions.

Stage 1.—Development of Secondary Hornblende ; Original Texture Preserved

In the rocks least affected by Laxfordian metamorphism, the minerals and texture of the original dolerite are well preserved. Pyroxene (augite, and often hypersthene) and labradorite or andesine felspar are still the most abundant minerals, but secondary hornblende and rare secondary biotite are present.

The hornblende forms narrow rims (0·5 mm.) separating pyroxene or iron oxides from felspar. It is a dark bluish-green, strongly pleochroic, variety. A large part of each rim extinguishes at once, and seems to be part of a single crystal. Biotite, when present, is usually associated with ilmenite.

The felspar laths have a core which is misty with minute inclusions, surrounded by a clear and somewhat more acid rim. MacGregor (1931) ascribed the clouding of felspars in a dyke at Scourie to thermal metamorphism. The phenomenon is, however, widespread throughout the least-altered dykes, and appears to be a normal part of regional Laxfordian metamorphism. The majority of the felspars show signs of considerable deformation and are bent and strained.

An interesting feature of this stage is the sporadic development of garnets which occur either as reaction rims separating the felspars from the mafic minerals, or as large grains which are in some cases arranged in lines following cracks. A section of a stringer of garnet from the " Scourie dyke " described by Teall (1885) shows the mineral, associated with red-brown biotite, clearly replacing the pyroxenes and felspar of the dolerites. The significance of these garnets is obscure, but their localization along cracks suggests that circulating solutions may have played a part in their formation.

Although the changes outlined above are referred to here as forming the first stage of Laxfordian metamorphism, the possibility that they, and the changes in the second stage described below, are in fact due to autometamorphism cannot be ignored. Whereas metadolerites in the third and later stages show a definite geographical distribution, related to the position of the Laxfordian front of metamorphism, the first and second stages are found sporadically over much of the area between Scourie and Ullapool where the influence of the Laxfordian metamorphism is very slight. Since the whole area is crossed by Laxfordian belts of shearing, it is reasonable to suppose, however, that the front of metamorphism lies at no great distance above or below the present land surface. If this is the case, it is not unreasonable to expect that the dolerites of the region should show a very slight degree of Laxfordian metamorphism.

Stage 2.—Replacement of Pyroxene by Quartz-hornblende Aggregates ; Original Texture Preserved

In the second stage of metamorphism, all the primary pyroxene disappears. The felspar laths, apart from slight sericitization, remain substantially unaffected, and show as before a clouded core and a clear rim. The pyroxenes are pseudomorphed by aggregates of hornblende and quartz ; the texture of the rock, as seen in hand specimen, remains unchanged. Each quartz-hornblende aggregate is bounded by the rim of hornblende developed in the previous stage. The central grains are smaller and paler in colour than the rim and are associated with numerous small grains of quatrz. As metamorphism proceeds, all the hornblende grains of an aggregate unite to form a single grain sieved with many droplets of quartz. Ilmenite grains become rimmed

with small grains of sphene. Slight differences between the meta-dolerites of Loch Torridon and Scourie can be detected at this stage of metamorphism. In the former locality, the amphibole tends to be paler and somewhat elongated, while at Scourie it has a deeper colour and forms rounded grains. Occasional flakes of chlorite are associated with the hornblende aggregates at Loch Torridon.

The association of two slightly different hornblendes in the aggregate replacing pyroxene calls for some comment. The outer rim, which is the first to form, is somewhat darker and is not associated with quartz. The central grains are at first smaller and paler, and are associated with quartz. The first type normally occurs at the contact between pyroxene and plagioclase, and it is reasonable to suppose that it was formed by reaction between these minerals ; its rather bluish-green colour may be due to the incorporation of some soda from the felspar. The formation of the hornblende in the centre of the aggregates probably took place without reaction with the felspar, and quartz was a by-product of the process.

Stage 3.—Recrystallization of the Felspar ; Original Texture Modified

The third stage of metamorphism results in the recrystallization of the felspar. Each lath divides into several equidimensional grains. In many cases the grains occupy the place of the original crystal and there is little change in the megascopic appearance of the rock ; in other cases, the effects of stress have been sufficient to deform the original mottling of the rock and draw out the felspar groups into streaks. The new felspar grains usually have the composition of andesine. The clouding of the mineral disappears with recrystallization.

The hornblende aggregates become darker in colour and more robust and begin to encroach on the felspar areas. The conversion of ilmenite to sphene continues. No chlorite occurs in any rocks of this stage.

Stage 4.—Recrystallization of Hornblende-quartz Aggregates ; Original Texture Destroyed

In the fourth stage of metamorphism, all traces of the original texture are destroyed by the complete recrystallization of the rock. A very marked change in its megascopic appearance takes place. A planar or linear orientation of the hornblendes is developed and the blurred appearance produced by the minute hornblende and quartz grains of the earlier stages is replaced by an evenly granular texture. The mottling of light and dark minerals which was inherited from the original dolerite entirely disappears.

In section, the rock has a grain size of 0·5–1·0 mm. Hornblende forms elongated grains, slightly darker than before, showing the pleochroic scheme blue-green–olive-green–straw-coloured. The abundant inclusions of quartz have almost entirely disappeared and the hornblende is compact and well-formed. Quartz, now no longer enclosed by the hornblende, forms fairly abundant grains. The plagioclase lies on the border between andesine and oligoclase. Aggregates of granular sphene have now almost entirely replaced the original ilmenite.

Large and abundant garnets are locally developed at this stage of metamorphism. In the area south of Loch Laxford, segregations of garnet, with quartz or felspar, reach a foot or more in diameter. The formation of these bodies shows that considerable freedom of diffusion, related to the increasing intensity of metamorphism, has been attained.

With this stage showing complete recrystallization of the metadolerites, the petrographical description of these rocks can be brought to a close. Although many further changes take place in the higher grades of metamorphism, they are not relevant to the purpose of this paper which is to compare the beginning of the metamorphic process in a number of different geological settings.

Laxfordian Metamorphism of Dolerites within Shear-belts

In the outer zones of Laxfordian metamorphism, belts of very intense shearing traverse the complex. It appears that the rigid mass of Scourian rocks, when subjected to stress, broke into great lenticular fragments which slid past one another. Within the belts of shearing, which range from a few feet up to thirty yards in width, all rocks are recrystallized and metamorphosed. Earlier structures are deformed and pulled round into parallelism with the shear-belts and a strong foliation and lineation are developed. Dolerite dykes have often acted as lines of weakness along which movement took place, and a shear belt may follow a dyke for a mile or more. In other cases, shear-belts running obliquely to a dyke displace the dyke or throw it into isoclinal folds.

The metamorphism of a dolerite in a shear-belt near Scourie was described by Teall (1885) and the reader is referred to Teall's paper for a detailed description of the process. For the purposes of this present discussion, it is sufficient to state that metamorphism produces strongly foliated and lineated rocks consisting mainly of hornblende, andesine, or oligoclase and quartz, with accessory biotite and rare epidote and scapolite. Chlorite, albite, and calcite are absent.

The shear-belts traverse dolerites which normally show only a very ow degree of Laxfordian metamorphism. It is reasonable to attribute

the much higher grade of metamorphism developed within these narrow belts largely to the effects of movement which either directly or indirectly, by facilitating the circulation of fluids, allowed reactions to proceed more rapidly. It is unlikely that there can have been much difference in the temperatures inside and outside the shear-belts.

It is a point of great interest that the minerals developed in the shear-belts are the same as those found in the regional metamorphic series described above. It must be assumed that although the application of strong stress greatly accelerated the process of metamorphism, it did not alter its course. This is a point of some significance in connection with the nature of the Banffshire epidiorites which are discussed on a later page.

Epidiorites of the Southwest Highlands

The metadolerites dealt with by Wiseman from the Southwest Highlands (1934) differ in the early stages of their metamorphism from the Laxfordian dolerites described above. The stages recognized by Wiseman may be summarized as follows :—

(1) Chlorite, pale green hornblende, albite, and epidote replace the augite and labradorite of the dolerite. Traces of the original texture are still recognizable. These changes take place in the chlorite and biotite zones of the associated pelitic rocks.

(2) Chlorite disappears ; albite and epidote react to produce oligoclase or andesine ; garnet appears locally. (Garnet zone of pelitic rocks.)

(3) Epidote tends to disappear and augite locally begins to replace hornblende. (Sillimanite zone of pelitic rocks.)

It will be seen that the first products of metamorphism are albite, epidote, and chlorite. Wiseman considers that the early-formed hornblende may be only metastable, and that it would disappear if complete equilibrium were reached ; this hypothesis is strengthened by the absence of hornblende from the chemically similar Green Beds.

The first products of metamorphism of the sills are thus totally different from those of the Laxfordian metadolerites where albite or epidote do not appear and chlorite is absent from all except a few of the Loch Torridon dykes. Later metamorphism follows a similar course in both areas and culminates in the appearance of augite.

Pyroxene-bearing Metadolerites

Metadolerites whose metamorphism is characterized from the first by the presence of pyroxenes have been described from a number of regions in all of which they have very similar characters. In these rocks, the original pyroxene becomes surrounded by a rim of small pyroxene

grains and, as metamorphism proceeds, the whole of the original grain is replaced by a granular aggregate of augite or diopside, sometimes accompanied by enstatite and garnet. The ophitic texture is frequently preserved in the early stages. When recrystallization of the felspar occurs, it is not accompanied by a marked change in composition. Small quantities of hornblende and biotite are frequently present, but they are not intermediaries in the formation of the new pyroxenes, being in some cases actually later than the pyroxenes, and formed from them in the waning phases of metamorphism.

Metadolerites of the type outlined above have been described by Stillwell (1919) from Cape Grey in Adelie Land, where they traverse cordierite-gneisses of sedimentary origin ; by Tilley (1921) from the Eyre Peninsula where they are enclosed in hornblende, biotite, and charnockitic gneisses ; and by Temperley (1938) from Tanganyika where they are again enclosed in granitic and charnockitic gneisses.

Discussion

The facts given in the previous pages are summarized in the diagram (Text-fig. 1), which sets out three of the possible lines of evolution of metadolerites. It is very probable that other series, not mentioned in this paper, exist, and that the diagram is therefore incomplete.

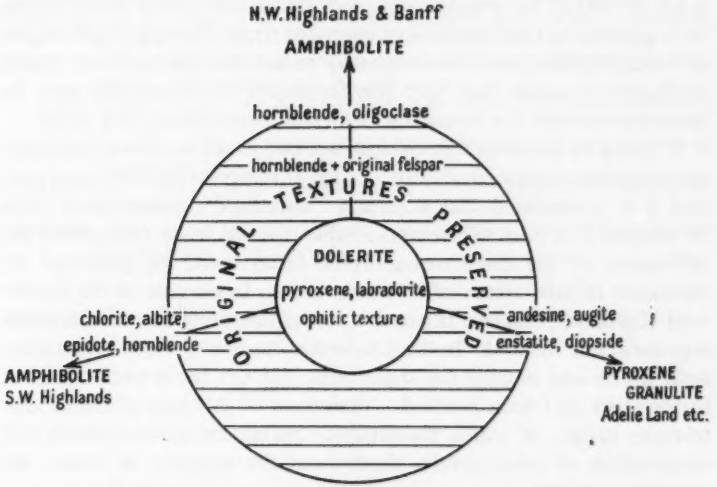
Since, in each series, the primary doleritic texture can still be recognized in the early stages, it cannot be suggested that the three groups merely represent random samples of a single progressive series. It is clear that the metamorphism of dolerites can follow at least three alternative courses.

The geological setting of the majority of cases under discussion suggests that in each instance metamorphism was of regional type. The metadolerites of the Southwest and Northwest Highlands are involved in the general Dalradian and Laxfordian metamorphisms respectively. The metamorphism of the dolerites of the Eyre Peninsula is ascribed by Tilley to the contact action of the granite-gneisses that surround them, and should therefore perhaps be omitted from this discussion. It is, however, of a very similar nature to that described by Temperley and Stillwell, which is of regional type.

It appears, therefore, that although great variations in the course of metamorphisms are to be found in different localities, they are all due to processes which fall within the broad division known as regional metamorphism, and it is to variations within this division, and not to such divergent phenomena as pure thermal or dislocation metamorphism, that they must be attributed.

The peculiarities of the metamorphic rocks of Banff and Aberdeenshire, where large areas of pelitic rocks are characterized by the presence of andalusite, were regarded by Harker (1932) as being due

to a deficiency in the stress factor of regional metamorphism, and Wiseman accepts this hypothesis as an explanation of the " anomalous " nature of the metadolerites of the region. In the Laxfordian complex, where the metamorphism of the dolerites follows the same trend as that in Banff, the application of very strong stress within the shear-belts does not cause a reversion to the type of metamorphism found in the Southwest Highlands. The minerals which are formed in the regional series are produced also under conditions of intense stress.



TEXT-FIG. 1.—Three lines of evolution of metadolerites.

It is clear, therefore, that variations in the stress factor alone are not competent to explain the existence of more than one metamorphic series in the dolerites.

The divergent trends of dolerite metamorphism seem to reflect comparable variations of the metamorphic provinces in which the different groups occur. The sequence described by Wiseman, in which chlorite is the first-formed femic mineral, is found in an area in which the pelitic rocks develop the index minerals chlorite, biotite, garnet, kyanite, and sillimanite. This sequence is therefore connected with the type of metamorphism developed in the Southwest Highlands. In the Dalradian rocks of Banffshire, however, metamorphism took another course ; the first new mineral to be formed in the dolerites was hornblende, and the pelitic rocks do not conform to the zones of Barrow but are characterized by andalusite and cordierite.

The metadolerites of the Laxfordian area are similar to those

of Banffshire, but in this case the country-rocks are biotite- and hornblende-gneisses and no pelitic rocks are available to provide a basis for comparison with the Dalradian assemblages. Although kyanite-gneisses are known in the Northwest Highlands, it is not certain that the kyanite is of Laxfordian age.

Metadolerites in which the first new femic mineral is a secondary pyroxene have been found only in extensive areas of gneisses which are often charnockitic in character.

If the metamorphic history of the doleritic rocks can be used as a key to that of the metamorphic province in which they occur, it may be suggested that sedimentary or gneissose rocks showing a high degree of metamorphism have not necessarily passed through the lower grades of Barrow's series, and that the formation of migmatites may be unconnected with the formation of biotite- and chlorite-zone rocks.

If it may be assumed that chlorite can be formed at a lower temperature than hornblende, and both at a lower temperature than pyroxene, and if it is admitted that a certain " threshold " temperature must be reached in a rock before appreciable reaction takes place, then the differences of the three metamorphic series could be produced by variations of this " threshold " temperature. In the case of the Southwest Highlands, reaction began at a low temperature at which chlorite was the stable mineral. In the Laxfordian complex, effective reaction, both inside and outside the shear-belts, did not begin until a higher temperature had been reached. Variations of this sort might be due to many causes, of which the depth of burial, the concentration and composition of intergranular fluids, and the intensity of stress are possible examples.

A consideration of the facts given above leads to the conclusion that all regionally metamorphosed rocks cannot be regarded as members of a single series. It follows that no metamorphic rock can be looked on as abnormal or anomalous because it fails to conform to types shown to exist in another area. Barrow's zones in the Southwest Highlands, for example, are only one of a number of possible trends of metamorphism, none of which is anomalous when regarded in the light of the geological setting in which it is found.

In the cases outlined above, it is clear that the least-altered Laxfordian metadolerites, whose mineral assemblage corresponds roughly to that of Wiseman's metadolerites in the garnet zone, have never passed through a stage in which they possessed the minerals found in Wiseman's metadolerites of the chlorite and biotite zone. The view that all zones of regional metamorphism are not genetically connected has long been held by Read (e.g. 1939) who has pointed to the perfect preservation of sedimentary textures in highly metamorphosed rocks, in contrast to the destruction of such textures in the lower grades of

metamorphism. Such a view accords well with the thesis of this paper and provides a fruitful hypothesis by which such problems as the relations of the granulite and amphibolite facies might be explored.

REFERENCES

HARKER, A., 1932. *Metamorphism.* Methuen.

MACGREGOR, A. G., 1931. Clouded feldspars and thermal Metamorphism. *Min. Mag.*, xxii, 524.

READ, H. H., 1923. The Geology of the country around Banff, Huntly, and Turriff. *Mem. Geol. Surv. Scotland.*

—— 1939. Metamorphism and Igneous Action. *Brit. Ass. Section C.*

STILLWELL, F. L., 1918. The Metamorphic rocks of Adelie Land. *Australian Antarctic Exp.* 1911–1914 *Sci. Rpts. Ser. A*, iii, pt. i.

TEALL, J. J. H., 1885. The metamorphosis of dolerite into hornblende schist. *Quart. Journ. Geol. Soc.*, xli, 133.

—— and Others, 1907. The geological structure of the Northwest Highlands of Scotland. *Mem. Geol. Surv. Scotland.*

TEMPERLEY, B. N., 1938. The Geology of the country around Mpwapwa. *Tanganyika Geol. Surv. Short Paper No* 19.

TILLEY, C. E., 1921. The granite gneisses of Eyre Peninsula and their associated amphibolites. *Quart. Journ. Geol. Soc.*, lxxvii, 75.

WISEMAN, J. D. H., 1934. The Central and Southwest Highland Epidiorites. *Quart. Journ. Geol. Soc.*, xc, 354.

Permian Rocks of the Midlands

By W. S. Boulton

Abstract

During the Permian the time involved in orogeny, erosion and deposition of continental and marine deposits, and the evolution of its characteristic faunas and floras, is comparable with that of other established Systems. The Permian in the Midlands has been for many years officially classed with the Carboniferous or Trias, in some cases with a query, separated by a great unconformity. It is now urged that it should be separately represented, and include all the deposits in the Midlands from the base of the Enville Beds to the top of the "Dune Sandstone", now called Lower Mottled Sandstone of the Trias.

FOR many years the sequences and relationships of the rocks between the Carboniferous and Trias in the Midlands have been in dispute, chiefly due to the absence of fossils and the physiographic and climatic conditions under which they were deposited. This uncertainty is reflected in the maps and publications of the Geological Survey ; in a few cases certain deposits are called Permian, while rocks assigned to the Permian by other workers have been placed by the Survey either in the Carboniferous or Trias.

The one-inch map of Birmingham published in 1924, has the Enville and Clent Group linked with the Carboniferous marked with a query, and the Hopwas Beds with the Trias, with a great unconformity between them. The Dudley sheet, 1949, Stafford map, 1927, Wem map 1924, show the Enville Beds all queried Carboniferous, while in the Lichfield map, 1922, the Hamstead (Enville) is left unclassified. Where the Hopwas Beds are present they are put with the Trias.

In contrast, the Survey memoir, 1948, on the Geology of Southport and Formby, gives the details of the D'Arcy Exploration Co. bore-holes in the Formby District, carried out since the re-survey of the area was completed. These bore-holes record a thickness of Manchester Marls from 410 to 740 feet, and the underlying Collyhurst Sandstone from 1,165 to 2,345 feet. The results show that "The Permian rocks of the Formby area vary in thickness from about 1,900 feet at Scarisbrick to about 2,750 feet in the vicinity of Formby" (p. 5), the cover of Trias being over 3,000 feet thick.

It was this uncertainty of the Permian in British geology which led to the choice of the "Validity of the Permian as a system" as the subject for discussion at the B.A. Meeting in Bristol in 1930, printed in extended form in their Annual Report (1931).

Bernard Smith and R. L. Sherlock of the Geological Survey took part in this discussion, the former concluding that the issue of a separate system is primarily a question for foreign geologists where marine fossiliferous Permian rocks are known ; while the latter would

abolish the Permian as a system, not only in this country but abroad, joining some of its deposits with the Carboniferous, and the rest with the Trias as an Epiric System. Others who took part expressed very different views, and were convinced that the evidence for a separate system is overwhelming.

D. M. S. Watson was of opinion that the time necessary for the evolution of the Permian fauna in Texas, South Africa, and elsewhere represents a space of time as long as the Carboniferous. J. W. Gregory stressed not only the characteristic faunas, but the vast period of time involved in the great Altaid mountain making processes and their erosion. G. A. Hickling advanced similar arguments for its retention as a system, but suggests the necessity of recognizing the passage of some Permian into Trias and the use of the term Permo-Triassic in such cases. After referring to my work in the Midland Permian rocks, which are separable from the Carboniferous and Trias, and the fossiliferous Permian abroad, I urged that the time implicit in the crustal movements and eroded accumulations, and the evolution of its fossil organisms is comparable in extent with that of other well-established systems.

It is agreed that the interval between the Carboniferous and Trias was a great mountain making period, when this country and western Europe lay on the fringe of the Altaid mountain system. Towards the close of the Carboniferous the rocks of the south of England, South Wales, and south Ireland were uplifted in the Armorican folding and constantly eroded until the whole of the Carboniferous and Devonian or O.R.S. was worn away—a thickness of 8,000 to 10,000 feet—and the materials deposited mainly to the north. The base of the Trias resting on the Wenlock near Cardiff is some measure of the size of the unconformity (O. T. Jones, 1931). In the Midlands the Mercian Highlands east and south of Birmingham were uplifted and faulted, and their eroded material is now recognized as coarse and fine breccias, pebble beds, sandstones, and marls. Sand dunes accumulated in the low-lying rugged arid area west of the South Staffordshire Coalfield as far as the Wirral. These conditions persisted throughout the Permian, and in a modified form during the Triassic, until the Rhaetic and Lias sea invaded the area.

The physical and climatic conditions of this period are admirably described by Professor Wills in his *Palaeogeography of the Midlands*, published in 1948, and were referred to at the meeting of the British Association in Birmingham in September of last year, when the geology of the Birmingham District, and the conditions which led to the Hidden Coalfields in the Midlands were dealt with. In his book and at the B.A. Meeting, Professor Wills suggests the Permian age of the Lower Mottled Sandstone of the Bunter. It was refreshing to have that opinion

stated by an old Survey Officer, but it may be a wrench for the Survey, who for fifty years have tended to regard the Midland Permian rocks as of Carboniferous or Triassic age, to bring into the Permian the Lower Mottled Sandstone which for a century has been classed as part of the Bunter.

That the Lower Mottled Sandstone is of Permian age is not altogether a new idea. In the Memoir on the Concealed Coalfield of Yorkshire and Nottinghamshire, 1926 (p. 49), C. V. Wilson discusses the difficulties arising from the uncertain age of the Lower Mottled Sandstone and its apparent passage into Permian Marls, and says : " When the Upper Magnesian Limestone is absent the problem is much more difficult, and depends entirely on whether any of the Lower Mottled Sandstone of the district is really of Triassic age. If such is not the case it is perhaps best to fix the geological base of the Trias at the bottom of the Bunter Pebble Beds, and to regard any marls or mottled sandstone below that horizon as being of Permian age."

In a written contribution to the Discussion on my paper " The Breccia Bed underlying Nechells " in 1924, E. E. L. Dixon says (p. 372) :—" The close connection in Cumberland of the Permian breccia with the Trias—their lateral passage one into the other—the importance of which has been pointed out by Mr. Bernard Smith, emphasizes the conclusion of Binney, Wilson, Sherlock, Hickling, and others, that the Lower Mottled Sandstone of South Lancashire and Nottinghamshire is itself of Permian age. These are the areas of typical fossiliferous Permian and the nearest to the Midlands, and the classification of the Lower Mottled Sandstone of the Midlands is vitally affected thereby. The general constancy in character of the Lower Mottled Sandstone suggests that in default of strong evidence to the contrary, it is essentially one formation throughout, but, at the same time, its close resemblance to higher Triassic strata is dead against its reference to another system."

I differ with his last statement. The Upper Mottled Sandstone is similar to the Lower Mottled Sandstone chiefly in the red colour of the sand grains, but its sandstones and thin marls were deposited in an inland shallow water area above the Bunter Pebble Beds, whereas the Lower Mottled Sandstone, west of the South Staffordshire Coalfield and extending through the Bridgnorth area into Cheshire, is a deposit of desert sand dunes on a very irregular rocky floor, and, in consequence, of very variable thickness.

In describing the Barr Beacon Beds north of Birmingham (Boulton, 1933), I suggested that the loose irregularly deposited millet-seed sands, with quartzite breccia fragments, deposited along the western fringe of the Mercian Highlands, may be the time equivalent of the Lower Mottled Sandstone of the western Midlands.

The transfer of the Lower Mottled Sandstone to the Permian would remove difficulties of correlation in areas other than the Midlands. Hickling, in the Permian discussion at Bristol in 1930 (pp. 320, 321), cites the case near Manchester where Bunter sandstones, overlying fossiliferous Permian Marl with thin limestones rest in turn on Permian sandstones, and within twenty-five miles westward the marls and limestones thin out and become sandy, so that the underlying Permian sandstones are inseparable from the Bunter Lower Mottled Sandstone. He also refers to Bernard Smith's work in Cumberland, who showed that the Permo-Triassic sequence in that area is closely similar to that in South Durham, except for the great expansion of sandy beds, and thinning of limestones. Hickling suggests that, since at that time there was no physical barrier between the two areas, the replacement of a great thickness of limestone by sandy deposits suggests a lateral passage. In South Lancashire, the North of England, and South Nottinghamshire, the gradual passage of eolian sandy beds into Permian Marls and limestones is explained if the sands, marls, and limestones are different phases of the same deposit, and the sandy beds are Permian and not Trias in age.

In the Midlands the great unconformable overlap lies at the base of the Bunter Pebble Beds, which rests at different places on the Lower Mottled Sandstone, the Quartzite and Clent Breccias, Enville Beds, different members of the Upper Coal Measures, and the Middle Productive Coal Measures. The junction with underlying beds is generally very irregular, with fragments of the underlying rocks embedded in their basal beds. The scouring effect of the floods which carried the pebbles is seen in many places, as in the Barr Beacon Beds, where the loose, underlying sand is churned up and mingled with lenticles of pebble beds.

The bottom of the Midland Permian should be placed, in my opinion, at the base of the Enville Beds. When Arber in 1916 suggested grouping the red marls, sandstones, and Calcareous Conglomerates with the Clent Breccias and marls under the name Enville Series, he suggested that they are part of the Stephanian. The Survey have adopted the term Enville Beds for the group, which includes the Corley Beds of East Warwickshire, and they are placed provisionally with the Carboniferous.

Apart from fragmentary plant remains, the only fossils in these beds so far known are the footprints in the Hamstead (Enville) Beds, and the Labyrinthodont skull of *Dasyceps bucklandi*, and the maxilla of the reptile *Oxyodon* in the Kenilworth sandstones, all regarded as Permian. It may be added that the removal of the Enville Beds into the Permian will make the Carboniferous less unwieldy.

It is not possible to determine a detailed sequence between these

suggested upper and lower limits of the Midland Permian. The scree-breccias, sandstones, and marls, accumulated on a very uneven, rocky floor during a vast period of uplift, faulting and erosion of the adjacent Mersian Highlands, differ in their detailed local sequence. But it is possible to make out the following general upward succession :—

1. *Calcareous Conglomerate or Bowhill Group.*—Conglomerates with pebbles of Carboniferous Limestone and jasperized quartz, red sandstones, and marls. The Corley Conglomerate Group is probably related to the Bowhill Group.

2. *Clent Breccia Group.*—Clent, Lickey, Northfield, Nechells, Warley, Sutton Park, Hopwas, Enville, Kenilworth, with fragments of igneous rocks of Uriconian type, and Valentian sandstone and limestone. Moira Breccia outcropping between Coal Measures and Bunter Pebble Beds, and cores from the Chilcote Borings of igneous and Charnian rocks over 97 feet thick below Bunter Pebble Beds.

3. *Quartzite Breccia Group.*—Barr Beacon and Littleworth Beds. Borings and outcrops in Birmingham district, underlying Nechells Breccia and overlain unconformably by Bunter Pebble Beds.

4. *Desert Sand Dunes.*—(" Dune Sandstone " of Professor Wills, and same as the Lower Mottled Sandstone.) Enville, Brignorth, and Cheshire area. Possibly same age as Quartzite Breccia to the east.

When this Midland Permian has been satisfactorily correlated with the Permian of other districts, the British Permian System can be recognized as an arid continental phase of the Permian of other countries, and should have its appropriate place in official publications and maps.

REFERENCES

BOULTON, W. S., 1924. On a Recently Discovered Breccia-Bed underlying Nechells. . . . *Quart. Journ. Geol. Soc.*, lxxx, 343–365.

—— 1933. The Rocks between the Carboniferous and Trias in the Birmingham District. *Quart. Journ. Geol. Soc.*, lxxxix, 53–82.

DIXON, E. E. L., 1924. Discussion on Boulton's Paper (1924, *op. cit.*, p. 372).

HICKLING, G. A., 1931. *Report of Brit. Assoc.* (Bristol, 1930), 320–1.

JONES, O. T., 1931. Pres. Address, Section C, *Brit. Assoc. Report* (Bristol, 1930), 58.

WILLS, L. J., 1948. *The Palaeogeography of the Midlands.* Liverpool Univ. Press.

WILSON, C. V., 1926. Concealed Coalfield of Yorkshire and Nottinghamshire (2nd Ed.). *Mem. Geol. Surv. England and Wales.*

Wave Action in Shore Platform Formation

By A. B. EDWARDS

(PLATES IV AND V)

ABSTRACT

Erosion of headlands along the southern coast of Victoria results chiefly from the attack of storm waves, and is concentrated above a defined level, marked by certain level shore platforms, whose surfaces are at about high tide level. These platforms are initiated and maintained by storm wave erosion. Their surfaces undergo planation and lowering, chiefly by the scouring action of waves of translation, but increasingly by water-layer weathering as the platforms age and widen.

IN a recent paper in this Magazine reviewing the processes operative in the formation of shore platforms (Hills, 1949), the role of wave action was minimized in favour of other processes, notably that of water-layer weathering. Some restatement of the case for wave action as a major factor both in the primary development of these platforms and their subsequent planation seems warranted. The evidence offered below relates specifically to platforms cut in Tertiary basalts and Jurassic sediments along the southern coast of Victoria, on sections of the coast that are exposed to severe storms, and which have been described elsewhere as " storm-wave platforms " (Edwards, 1941, 1942, 1945).

Figure 1 (Plate IV) shows such a platform cut in Jurassic arkose and mudstone on a headland midway between Inverloch and Cape Paterson, and is typical of the platforms cut in these rocks on headlands along the South Gippsland coast. Such " unit " platforms are found as complete forms only where the coastline is sufficiently indented to consist of cliffed headlands separated by bays with bay-head beaches. The flat platforms jut out from the base of the cliffs, and end in sharply defined outer edges or " low-tide cliffs ". They tend to be widest in the front of the headlands, and decrease in width and often in height, when followed into adjacent embayments. They also tend to be wider the lower the cliffs. The surfaces of the platforms are some feet above mean low tide level, and are commonly covered by a foot or more of water during high tides, though they may remain exposed or partly exposed during periods of neap high tides. The surfaces are relatively smooth, though harder strata tend to project above the general level, particularly if their dip is steep. At the seaward edge the surface may be irregular, and above the general level of the platform. This feature of the surface is commonly referred to as a " rampart ". It should be emphasized that the rampart is a far from universal feature of the platforms. At the foot of the main cliff, the surface of a platform may slope gently upwards to form a ramp. The width of

the ramp varies greatly. It is rarely strongly developed on platforms like that shown in Fig. 1, Pl. IV. The form of the seaward edge varies. It may be abrupt, or even locally undercut, or it may slope down as an irregular wave-quarried ramp.

Along the less strongly indented Otway coast (between Point Castries and Cape Otway), where the rocks involved are identical Jurassic arkoses and mudstones, but with a prevailing seaward dip, the platforms tend to be continuous between the occasional indentations, except in so far as they are breached by channels along major joints or soft strata. The other features of the platforms are similar to those of the "unit" platform of Fig. 1, Pl. IV (Jutson, 1949). Ramparts are developed irregularly and discontinuously, and are absent from approximately 75 per cent of the seaward margins. Ramps are more prominent, ranging in width from a few feet to 40 feet. The back of the flat platform and the greater width of the ramp is hidden frequently by a sheet of sand, six inches to a foot thick. This sand cover is stripped off by some storms and tides, and returns with others. Residuals of hard beds, and calcareous concretions stand up above the otherwise smooth surfaces of the ramps and platforms. The platform surfaces are generally much smoother adjacent to the ramp, where they are intermittently sand covered, than towards the seaward edges where they are broken by channels and pools, or interrupted by ramparts.

Between these two sections of the coast lie the basalt coastlines of Phillip Island, at the mouth of Western Port Bay, and the south coast of the Mornington Peninsula, extending from Flinders to Cape Schanck. These parts of the coast are fronted by platforms similar to those described above (Figure 2, Plate IV).

Wave Conditions along the Victorian Coast

Prevailing Conditions.—The prevailing condition of the sea along the southern coast of Victoria is a state of swell that gives rise to breakers from three to six feet high, but does not mask the tidal rise and fall of sea-level. At low tide the waves break some distance out from the low-tide cliffs of the platforms, churning up sand, which is swept against the low-tide cliff. Kelp barriers afford some protection, but even on days of near calm, sand can be recovered from water swirling against the low-tide cliffs. Kelp growths extend over the sea floor for up to one mile off-shore to depths of 50 feet.

At high tide the waves break closer in, tending to trip on the kelp barrier fringing the low-tide cliffs, or on the low-tide cliffs themselves, particularly during flood tides. Less sand is churned up on the fronts of the platforms, but water pouring on to the platforms brings some sand with it. Waves racing obliquely along the sides of the platforms

pass the kelp zone, and churn up sand which may be carried on to the platform, the extra abrasion accounting for the lower elevation of the platforms towards the bayheads. *Hormosira* colonies (sea-grapes) described by Hills (1949) as coating platforms cut in dune limestones at Point Lonsdale and Sorrento, on either side of the entrance to Port Phillip Bay, are not strongly developed on the platforms under discussion, and when present act as sand traps. Mussel colonies are not strongly developed, but when present also act as sand traps.

When the platform is covered by water, sand on the ramp and the platform is swirled about by small translatory waves running over the surface of the platform. The water generally returns via the sides of the platforms and along joint channels, so that the back of the platform is more severely scoured than the forward part. As Jutson (1949) notes, the scour tends to undercut the inner margin of a rampart, if one is present, or of hard strata which obstruct direct return of the water to the sea.

During periods of weak tides, as in January and February, the platforms remain uncovered, or are only partially covered at high tides, unless a strong sea is running, and the small waves of translation that cross the platform either just reach the foot of the main cliff or commonly reach only to the foot of the ramp. During spring tides, however, the platforms are well covered at high tides, so that waves surge up to and against the base of the main cliff, and abrade it. When the swell is moderating, or when there is a strong off-shore wind the water commonly does not reach the foot of the main cliff at high tide.

It is under these conditions of varying attack that ramps are formed. The intensity of attack on the main cliff is largely controlled by the width of the platform, other factors being equal. Where the platform is narrow the high tide waves, or translatory waves resulting from them, consistently erode the cliff base and the ramp is narrow. Where the platform is wider, the attack is intermittent and sand tends to accumulate intermittently on the back part of the platform and the ramp.

Storm Conditions.—During the severe storms to which these coasts are subject, particularly at the equinoxes, when the tides are strong, conditions of wave action are very different. Both the main cliff face and the low-tide cliff face are attacked, but the main cliff receives the brunt of the attack. A combination of long fetch, strong winds, and possibly the V-shape of the south-central coast of Victoria between Cape Otway and Wilson's Promontory tends to cause a piling up of water against the coast, raising sea-level somewhat during storms. As a result of the height of the waves, the platforms are under water at both high and low tides during storms, and waves break close in.

Kelp is torn loose in quantity, and from being a protective agency becomes a factor in erosion. Counts of holdfasts on the shore after storms have shown that over 90 per cent of them carry attached pieces of stone from a few ounces to about 20 lb. in weight.

Wave Action and the Maintenance of Platforms

An essential condition to the continuing existence of a platform is that the rate of erosion of the main cliff should equal or exceed that of the low-tide cliff. Since generally, the main cliff is much the higher of the two, much more energy must be expended in its erosion than on erosion of the low-tide cliff, provided the rocks involved are of equal toughness and hardness.

In sheltered regions, as within Western Port Bay, where wave attack is of greatly reduced intensity, rock weathering develops down to the water level faster than erosion of cliff faces. Thus at Corinella Point, basalts in the cliff are completely weathered down to high water level, whereas at platform level and below the basalt is fresh. The softness of the rock in the cliff offsets the weakness of the wave attack, and a high steep face is maintained, even though the total energy expended on eroding the main cliff is possibly less than that acting more continuously but with much less effect on the low-tide cliff.

Along the coasts under discussion, however, recession of the main cliffs takes place more rapidly than the rocks weather. Where the coastline is cut in basalt, relatively fresh rock extends from top to bottom of cliffs up to 200 feet high, and except for interruptions by softer flow tops and bottoms, and in places tuff bands, is as hard and tough as the rock exposed in the platforms. On exposed stretches of coastline cut in Jurassic sediments erosion of the main cliffs is even more rapid, since minor intermittent streams are either left hanging, or descend the cliffs by extremely steep rapids. Weathering in the Jurassic sediments is readily detected by a colour change from the prevailing grey-green of the fresh arkose and the blue-grey of the mudstone to buff and yellow as the rocks become oxidized. The tops of cliffs 100 or more feet high show weathering for a considerable depth, but in the sections rising up from the platforms, and especially in cliffs backing narrow platforms, weathering is not pronounced, and the rocks appear to be not greatly inferior in hardness and toughness to those in the platforms and in the low-tide cliff faces. With increasing width of platform the degree of weathering in the cliffs increases, facilitating their erosion, and thus balancing the weaker attack of waves.

Evidence has been presented of the rapid retreat of these cliffs, whether in basalt or arkose, over considerable distances (Edwards, 1942, 1945), so that the continued existence of the platforms, with residues of earlier platforms out to sea, indicates that an equilibrium

has been achieved between the erosion of the main cliffs and that of the low-tide cliffs. The equilibrium is, of course, subject to constant adjustment by such changing factors as cliff height and rock hardness (Edwards, 1941).

In the preceding section it was indicated that under the prevailing conditions of wave attack, the low-tide cliff is subjected to much more continuous erosion than the main cliffs, and that it is only during periods of storm that vigorous erosion of the main cliff occurs. It is argued, therefore, that storm wave attack is essential to the continued existence of the platforms, and is in fact the one *positive* or constructive process in platform building. All the other processes enumerated by Hills (1949) are *negative* or destructive processes.

The Initiation of Platforms

Can wave action initiate platforms? Hills (1949, p. 149) suggests that it cannot "because the formation of such a platform would require maximum erosion at a defined level, which is not expectable with variation in wave height, also because the seaward edge of the platform would surely be more eroded than the landward, and again, because even in a tideless sea, with waves of constant height, the dissipation of energy in waves of translation requires that they form a ramp sloping seaward".

As indicated above, under normal weather conditions, erosion is concentrated on the seaward edge of platforms. Even so this edge is commonly not a sloping ramp, but sufficiently sharply defined to warrant the term "low-tide cliff" (cf. Hills, 1949, p. 138). Since equilibrium is maintained between the rates of retreat of the two cliff faces, and since erosion of the main cliff generally requires the removal of a far greater volume of more or less equally resistant rock than does erosion of the low-tide cliff, there must be a concentration of erosion at higher levels during abnormal conditions, namely, periods of storm. It is an observable fact that the main cliffs are eroded chiefly during storms. It is necessary, therefore, to distinguish between *frequency* of wave attack and *vigour* of wave attack. The frequency of wave attack appears to increase with decreasing level, since all waves at low tide, in normal weather, attack the low-tide cliff, whereas during many periods of high tide, there is little or no attack on the main cliff, although it continues on the low-tide cliff.

The maximum vigour of wave attack occurs during the infrequent storms, and as indicated, is predominantly at a level so raised that it brings the brunt of the attack against the main cliffs. In fact, the greater the storm, the more vigorous the attack, and the higher the level at which it operates.

These conditions must have operated from the initiation of the

coastlines, so that it is possible to picture *maximum erosion above a defined level*, namely the level of the platform.

The hypothesis that wave erosion would give a ramp sloping seaward, and that modification of this ramp to a platform is brought about by subsequent processes, such as water-layer weathering (Hills, 1949, p. 149) lead to an unsupportable corollary. The presence of ramparts is significant in this connection, particularly if it is accepted that the rampart is preserved because it is wetted more continuously than the rocks behind it, so that it is less subject than they to weathering or other chemical destruction. Acceptance of this view carries the implication (Hills, 1949, p. 150) that ramparts " could no longer be regenerated if once removed by erosion ". If waterlayer weathering is the chief agent modifying a seaward sloping ramp to a flat platform, there is a further implication that the rampart marks approximately the original seaward edge of the sloping ramp, since this would be the only part of the ramp sufficiently continuously wetted to escape the action of water-layer weathering. This view of ramparts is difficult to accept when seawards beyond some ramparts there are flat-surfaced platforms awash or just under at low tide, which are presumably worn down seaward extensions of the present platforms. It is equally difficult to accept the view that platforms were not formed during the retreat of sections of these coasts over distances of up to a mile, but suddenly came into existence when the coastlines reached their present point of retreat.

Furthermore, where the vigour of storm wave attack, in particular, is reduced, as in the bayheads between platform-fronted headlands, seaward sloping ramps do form (Figure 1, Plate IV). In other words, where the energies of high-level attack and low-level attack are rendered more nearly equal, ramps result.

If the platforms fronting the headlands could be withdrawn without other change in present conditions, then the erosive forces acting there on the main cliffs would possess an *excess of energy* above that necessary to maintain the present equilibrium. This change of energy relations would be in the *reverse* direction to that which present conditions show make for a seaward sloping ramp. It is hard to escape the conclusion that this excess of energy, which must have been available at the initial formation of any wave ramp on the headlands, was a factor in cutting back the cliffs during storms at a level beyond the reach of swell waves, thus initiating the platforms. The platforms would widen, reducing the energy of the high-level attack, until a balance between energy and load was attained. The other main factor in locating the platforms—and the headlands—would be an optimum hardness of the rocks involved (Edwards, 1941).

If only swell waves were involved, no such disparity in erosive

energy could be expected ; but storm waves tip the energy equation strongly in favour of high-level erosion. It is argued, then, that storm wave erosion is the major factor in initiating as well as maintaining these platforms. For this reason the writer believes that the term *storm-wave platforms* is justifiably applied to these platforms, and provides " a nomenclature based on genetic conceptions ".

Ramparts

The presence of a rampart rising some feet above the level of the platform as a whole, suggests that the height of the rampart marks a minimum possible initial level for high-level wave erosion. This is implicit in Bartrum's (1935) and Wentworth's (1938) explanation of the preservation of ramparts through continuous wetting, and the conception that a rampart, once destroyed, cannot be rejuvenated.

The explanation that ramparts are preserved because they are wetted more continuously than the rocks behind them, and so rendered more durable, is unsatisfying. Other factors being equal, it leads to the conclusion that all platforms should have a more or less continuous line of ramparts, whereas along the coastlines under discussion there are more platforms without ramparts than with ramparts. The seaward edges of platforms without ramparts are even more continuously wetted than those with ramparts, and are not necessarily exposed to more vigorous wave attack. Ramparts must, then, have some additional cause. The most likely cause is a favourable combination of inherent rock hardness, suitable dip, and a position such that *scour on the inner side is directed away* from the rampart-bearing section of the platform. Many ramparts occur on sections of the platforms facing the direction of most persistent wave attack, and *least backwash.* The outer face of the rampart is consistently smooth-faced rock, reflecting the effects of sand abrasion, whereas the top and inner faces of those cut in Jurassic sediments are prominently honeycombed from spray-wetting, except along runnel-ways and other areas exposed to sand scour. Comparable honeycombing is found on other parts of the platforms, that are protected from scour, so that the ramparts are only intermittently wet. On many platforms, as Jutson (1949, p. 51) has noted, the inner edges of the ramparts are being undercut by sand scour which in the main is directed to the sides of the platforms.

Under these conditions of origin, ramparts are features that can be regenerated on the surface of the platform whenever a favourable combination of hardness and situation occurs. It is also possible to picture the rejuvenation of a rampart that had been more or less destroyed, if the development of a joint channel, or the erosion of a soft bed could divert further scour from it.

Planation of Platform Surfaces

In discussing the planation of platforms Hills (1949, p. 141) stresses the importance of water-layer weathering as a process in planing and lowering their surfaces, and suggests that " the waves of translation that pass over such platforms produce little or no effect in lowering their elevation ". To the writer this view of the relative importance of water-layer weathering and mechanical abrasion in the smoothing and lowering of the platform surfaces appears to be a correct assessment as concerns the present condition of wide platforms, but the emphasis must be reversed for narrow platforms, where the scouring effect of small waves of translation, sweeping sand across the platform surface can be frequently observed. Water-layer weathering is an active process on such platforms but is not sufficiently intense to mask the effects of vigorous scour. The undercutting of concretions, hard beds, and ramparts on their inner sides with the development of miniature ramps at the undercuts (Figure 1, Plate V) is evidence that wave action can play an active part in the planation and lowering of platform surfaces. Scour tends to be concentrated towards the back of platforms, so that as they widen, more and more of the outer (seaward) part becomes removed from scouring, and on these parts water-layer weathering becomes the dominant process.

In the course of widening, however, sand scouring by translatory waves was probably the dominant process, and water-layer weathering may be regarded as a subsequent process that increases in importance as the platform ages. Evidence of this course of events is provided by a study of honeycomb structures on platforms cut in the Jurassic sediments.

As indicated, honeycomb structure is best developed on the tops and inner sides of ramparts. It may also be pronounced on the lower part of the main cliff face, on surfaces not exposed to the abrasive action of running water. Traces of honeycomb structure can be found over most of the width of the narrower platforms, indicating the earlier activity of spray-wetting, or small-scale water-layer weathering. As one progresses towards the main cliff, the honeycomb structures are progressively eliminated. The sharp edges of their cell walls are first bevelled and then lowered, adjacent cells merge into larger less well defined cells, and finally only fragmentary residual cell walls remain. These ultimately give place to a smooth surface. Eventually honeycomb structure is eliminated from all parts of the platform surface that are subject to waves of translation, and is preserved only on sites that rise above the general level of sand scour, or are otherwise protected (Figure 2, Plate V). The elimination of honeycomb structure can be explained in part in terms of water-layer weathering, but the presence of sand, the undercutting, and the

FIG. 1.—" UNIT " STORM-WAVE PLATFORM.

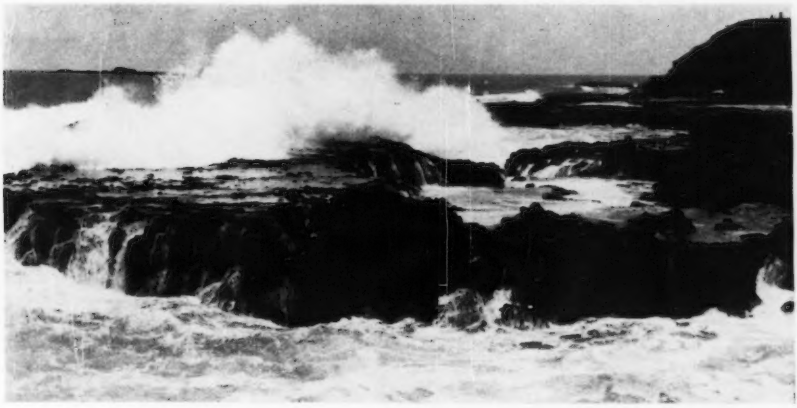


FIG. 2.—STORM-WAVE PLATFORM.

FIG. 1.—UNDERCUTTING BY SCOUR.

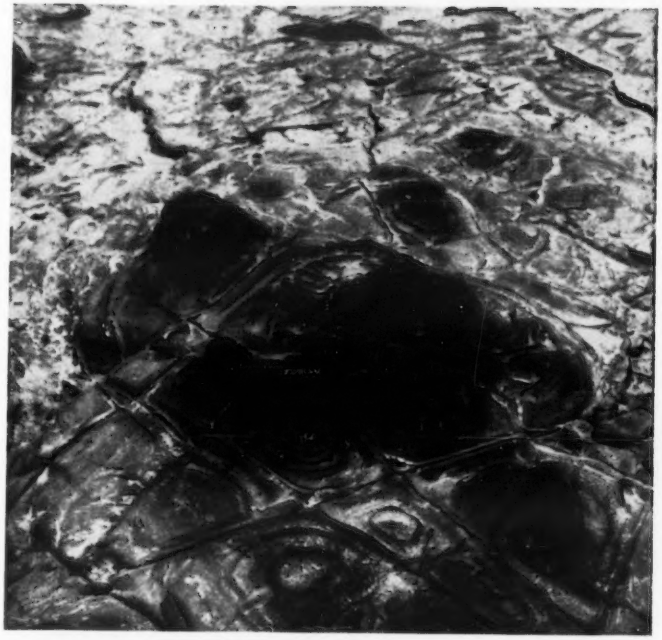


FIG. 2.—DESTRUCTION OF HONEYCOMB STRUCTURE.

often convex forms of the surfaces from which honeycomb structure has been eroded, point to the action of sand scour.

Conclusion

It is concluded that the conditions prevailing along the south-central coast of Victoria result in a concentration of storm wave erosion *above a defined level*, marked by the shore platforms under discussion, and that it is this vigorous high level erosion that initiated and maintains the platforms. Erosive forces other than storm waves are active simply in planing and destroying these platforms. Storm wave erosion being the one major constructive factor in the formation of the platforms, the term *storm-wave platform* is a correct genetic description.

The planation of such platforms is brought about largely by the scouring action of waves of translation, armed with sand and pebbles, traversing the platforms. Water-layer weathering increases in importance as the platforms are levelled and widened, and in favourable circumstances can become the dominant process in further levelling and lowering of platforms.

References

Bartrum, J. A., 1935. Shore Platforms. *Rept. Aust. and N.Z. Assoc. Adv. Sci.*, xxii, 135–143.

Edwards, A. B., 1941. Storm-Wave Platforms. *Journ. Geomorph.*, iv, 223–236.

—— 1942. The San Remo Peninsula. *Proc. Roy. Soc. Vict.*, liv, 59–74.

—— 1945. The Geology of Phillip Island. *Proc. Roy. Soc. Vict.*, lvii, 1–16.

Hills, E. S., 1949. Shore Platforms. *Geol. Mag.*, lxxxvi, 137–152.

Jutson, J. T., 1949. The Shore Platforms of Lorne, Victoria. *Proc. Roy. Soc. Vict.*, lxi, 43–59.

Wentworth, C. K., 1938. Marine Bench-Forming Processes : Water Level Weathering. *Journ. Geomorph.*, i, 6–32.

Explanation of Plates IV and V

Plate IV, Fig. 1.—" Unit " storm-wave platform fronting headland, and seaward sloping ramp at bayhead, developed in gently dipping Jurassic strata, midway between Inverloch and Cape Paterson, South Gippsland coast, at low tide.

Fig. 2.—Storm-wave platform cut in Tertiary basalt, south-west corner of Phillip Island, heavy swell at mid to low tide.

Plate V, Fig. 1.—Planation and undercutting of hard beds by scour, with residuals of honeycomb structure in protected places, and water-layer weathering rims around the flat calcareous concretions, which are being undercut by scour. Otway coast, near Kennet River.

Fig. 2.—Stages in the destruction of honeycomb structure on a platform surface, partly by water-layer weathering, partly by scour. A thin veneer of sand can be seen in the foreground. Otway coast, near Lorne.

Note on the Tectonic Style of the Ord Ban Quartzites, Mid-Strathspey

By Donald B. McIntyre
(University of Edinburgh)

Abstract

Study of profiles, perpendicular to the fold-axes, shows that the folding is disharmonic. Nearly every *s*-surface is one of *décollement*. In some exposures the quartzites are reduplicated by superposed recumbent-folds without infolds of other material. The contacts are tectonic and not stratigraphic. Incipient boudinage is frequent, and nearly all surfaces show well-developed *b*-lineation.

Setting

SILICEOUS and semi-pelitic granulites are widely developed in Mid-Strathspey. They belong to the Moine of the Central Highlands. Near Grantown these granulites enclose a group of pelitic, sometimes graphitic schists and gneisses with associated marbles and quartzites. Although the rocks of the Grantown Series are at a higher grade of metamorphism, they resemble the graphite-schist–marble assemblage of the Banffshire Dalradian, ten miles to the east. On the basis of this resemblance, E. M. Anderson suggested that the Grantown Series might be either an outlier or an inlier of Dalradian in the Moine (1915, p. 30). The present writer proposes to show in another paper that the Grantown Series is a gigantic tectonic inclusion enclosed in the Moine granulites. Thus added interest is given to Dr. Anderson's suggestion.

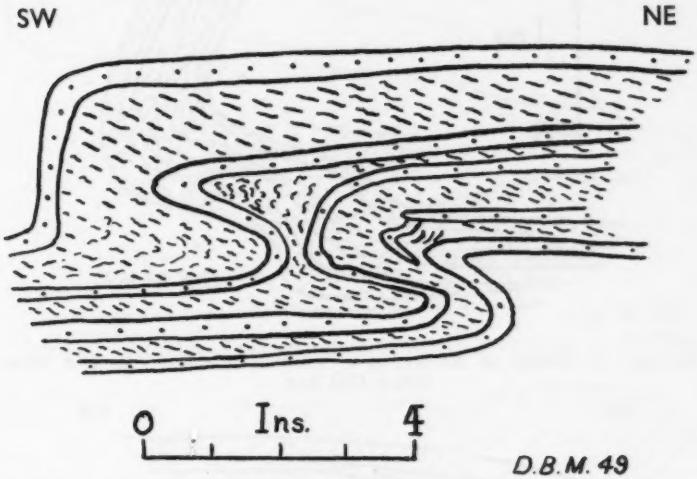
South of Grantown, in the Spey valley about Kincraig, a similar group of pelitic gneisses with associated marbles and quartzites is exposed. This group will be referred to as the Kincraig Series. It has not only the same lithological characters as the Grantown Series, but the same form and structural position. It is clear that both play a similar tectonic rôle. The relations and general characters of the two Series will be discussed elsewhere. The purpose of the present note is to record certain significant features of the tectonics of the Kincraig Series.

Folding and Décollement

Excellent exposures of the rocks of the Kincraig Series can be seen on the slopes of Ord Ban above Loch an Eilean, near Aviemore. Many of these are at right-angles to the fold-axes, and are very suitable for the study of the style. Bands of white quartzite are rather common, and the degree of their folding is spectacular. The plunge of the fold-axis is remarkably constant, but it does not coincide with that of the schists or of the marbles except where the latter are closely associated with the quartzites. A totally false impression of the style

is obtained if sections oblique to the fold-axis are taken. It is important that the sections be true profiles, exactly perpendicular to the fold-axis.

Disharmonic folding can be seen on most profiles (see Text-fig. 1). The reason for its prevalence is the close association of competent quartzite and incompetent mica-schist. Disharmonic folding implies



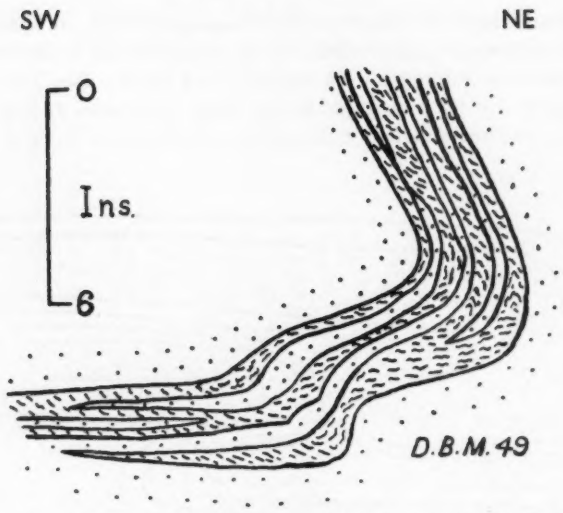
TEXT-FIG. 1.—Profile of disharmonic folding of siliceous granulite (dots) and mica-schist, Ord Ban.

at least a certain amount of *décollement* (" becoming unstuck "), and where it is abundant the contacts must be tectonic. Indeed, the mica-schist is sometimes intrusive.

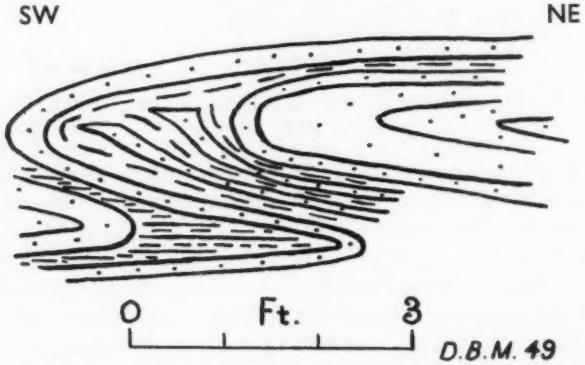
Many of the siliceous layers are discontinuous in profile (Text-figs. 2 and 3). This is a natural consequence of the differing behaviour of quartzite and mica-schist under deformation. Even more obviously than disharmonic folding, the discontinuity of the layers in profile shows that the majority, if not all of the contacts are tectonic.

Undoubtedly the most striking aspect of the style is the occurrence of superposed recumbent-folds in pure quartzite (Text-fig. 4). It is evident that quartzite can fold in this manner only if the quartz crystals are able to grow during the deformation. As Ellenberger has pointed out (1948, pp. 38, 62, etc.), recrystallization would give an effective plasticity to the mass as a whole. Where a thin band of mica-schist has been folded with the quartzite, the folding is conspicuous. But where the quartzite has been folded upon itself without infolds of other material, the complexity of the structure can easily be overlooked.

Superposed folds of this type cannot be produced without *décollement*

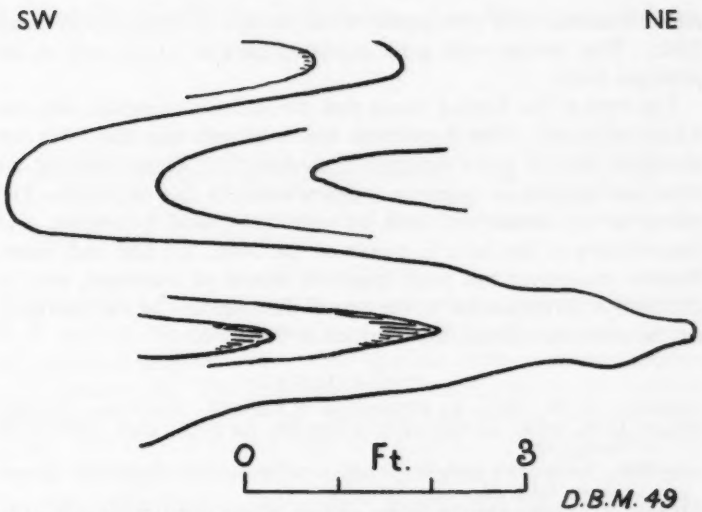


TEXT-FIG. 2.—Profile of discontinuous siliceous granulite (dots) in mica-schist, Ord Ban.

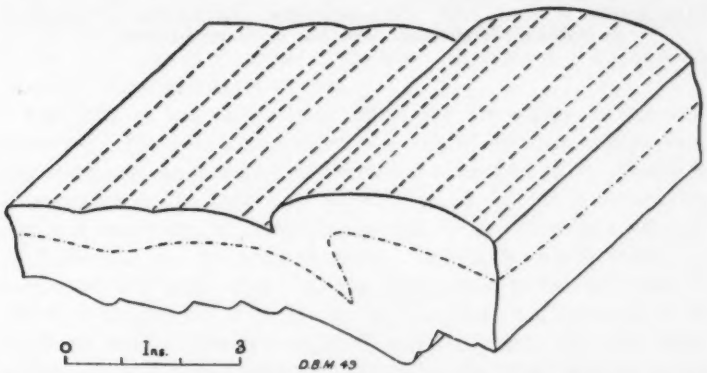


TEXT-FIG. 3.—Profile of discontinuous quartzite (dots) in mica-schist, Ord Ban.

and disharmonic folding. The contacts of the quartzite are tectonic and not stratigraphic. Indeed, the structure is reminiscent of George Barrow's " concertina-folding " (1904, p. 443). In the style envisaged by Barrow, each tectonic unit consisted of beds, folded upon themselves without infolds of other material, in a series of compressed isoclinal folds. Thus, the whole was made up of a series of superposed concertinas separated one from the other by tectonic contacts. The essential difference between the style of the Ord Ban quartzites and that of Barrow's concertinas, is that the close-packed folds are not vertical but recumbent.



TEXT-FIG. 4.—Profile of superposed recumbent-folds in quartzite, Ord Ban.



TEXT-FIG. 5.—Folding and lineation in quartzite, Ord Ban. The corrugation of the upper surface is greatly simplified in the figure.

The *décollement* is syngenetic with the folds themselves. These surfaces are therefore controlled by the same tectonic axes as the folds and there is no mylonite associated with them. Each surface is a miniature " slide " (Bailey, 1910, p. 593 ; 1909, pp. 53–4).

LINEATION

The Ord Ban quartzites show well-developed lineation. It is sometimes due to incipient boudinage (Text-fig. 4), but more frequently to regular ribbing (Text-fig. 5). There are, indeed, few surfaces without

good lineation. The ribs appear to be formed by the crests of small folds. They plunge with great regularity parallel to the axis of the principal folds.

The style of the folding shows that the fold-axis coincides with the *b*-kinematic-axis. The hypothesis which affirms that the folds are elongated parallel to the direction of transport (*a*), cannot account for either contraction or extension perpendicular to this direction. The piling up of recumbent folds on one hand, and boudinage and discontinuity of the beds in profile on the other, are just such cases. Relative movement has taken place on almost all *s*-surfaces, and its direction is perpendicular to the axis of the folds and to the lineation. On the scale considered, the lineation is thus in *b*.

REFERENCES

ANDERSON, E. M., 1915. *In*, Explanation of Sheet 74. *Geol. Surv. Scotland.*

BAILEY, E. B., 1909. *In*, Summary of Progress for 1908. *Geol. Surv. Great Britain.*

—— 1910. Recumbent folds in the schists of the Scottish Highlands. *Quart. Journ. Geol. Soc.*, lxvi, 586–620.

BARROW, G., 1904. On the Moine gneisses of the East-Central Highlands and their position in the Highland sequence. *Quart. Journ. Geol. Soc.*, lx, 400–449.

ELLENBERGER, F., *et al.*, 1948. Métamorphisme, Silicifications et Pédogénèse en Bohême Méridionale. *Ann. Sci. de Franche-Comté.*

A Xenolithic Sill at Tallabrista, Co. Donegal, Ireland

By Amin Gindy

(PLATE VI)

Abstract

An epidiorite sill emplaced in quartzites becomes charged with xenoliths of quartzite and of an amphibole-rich rock possibly derived from underlying limestone horizons. The matrix of the xenolith-rich part of the sill is studed with large hornblende-biotite "crystals" that may represent small limestone xenoliths that have been basified and homogenized.

Introduction

DURING a recent study of the metamorphosed Dalradian country-rocks of the area north-east of Gweebarra Bay, Co. Donegal,[1] two suites of igneous rocks earlier than the regional metamorphism were encountered. The first suite is now represented by the familiar dark-green or black epidiorites, the second by rocks of a lighter green colour. Members of the first suite were originally of doleritic composition while those of the second were possibly derived from pyroxene-bearing lamprophyres. The present average specific gravity of the first group is 3·000, of the second 2·737. At one locality (Pollnacally) it can be seen that members of the second suite cut epidiorite and are consequently younger. The aggregate volume of the earlier intrusions is very much greater than that of the later. Intrusions of transitional character occur but are very rare.

Xenoliths in the earlier basic intrusions are scarce in the area examined. The few found consist of a rock of the same composition and texture as the enclosing epidiorite but of coarser grain. Xenoliths in members of the later suite were observed only in a remarkable intrusion occurring on the sloping ground about 170 yards north-east of Tallabrista on the Atlantic coast. This body, which forms the subject of this paper, has a sill-like relationship to the quartzites in which it occurs, but it seems to become more transgressive at its southern end. Although regional metamorphism has now been impressed on country-rocks and sills alike, the main features of the Tallabrista intrusion are undoubtedly of primary origin.

The Normal Rock

At its northern end the sill is homogeneous and exactly similar to the other members of this suite. It is made up of a massive uniform rock with specific gravity of 2·822. It has a weak foliate element. In thin section, its groundmass is seen to be extremely fine grained, with an average grain-size of 0·03 mm., and made up of granular plagioclase (basic oligoclase to andesine) and quartz with very rare potash felspar. Small grains of amphibole, mostly hornblende with Z bluish-green, Y olive-green, and X pale yellow, are frequent in the matrix. Biotite, with Z = Y dull olivaceous green, X pale yellow, is present throughout in slightly larger flakes, rarely replaced by green

[1] Sheet 15, 1-in. series of the Geological Survey of Ireland, 1890.

chlorite. Pseudomorphs in amphibole and biotite, up to 7 mm. or more in size, are occasionally present and have an outline suggesting pre-existing porphyritic mafic minerals. These pseudomorphs are similar to those found in the other members of this suite. They have actinolitic hornblende and biotite in larger crystals than in the groundmass. Grains of sphene are sporadic, but tiny colourless epidotes, rarely with allanite nuclei, are common.

When this normal homogeneous sill is followed southwards along its extent down the sloping ground for a score of yards, it suddenly becomes charged with inclusions of quartzite and other rocks, and it undergoes changes which are described in detail immediately. Just before reaching this xenolithic portion, however, the rock of the sill, while still homogeneous, becomes distinctly coarser in grain and dioritic in appearance. The specific gravity of this coarse type is 2·711. In thin section, the rock shows the same mineral assemblage as the normal sill-rock, but the texture is different. Large partly idiomorphic plates of plagioclase, up to 5 mm. across, and amphibole-biotite pseudomorphs of a pre-existing mafic mineral form the dominant components. The plagioclase is poorly twinned, of an intermediate oligoclase composition and riddled by tiny droplets of quartz ; there are crude myrmekitic or micropegmatitic intergrowths between the quartz and felspar. Potash felspar is very rare and forms occasionally a crude intergrowth with the plagioclase. Quartz grains, up to 0·3 mm. in diameter, present a globular or bulbous outline, and may sometimes be a significant constituent of the rock. As in the normal rock, amphibole and biotite form large pseudomorphs but, in addition, small disorderly laths of tremolite, actinolite, and biotite occur in the groundmass. Further, small amphibole laths are found in the plagioclase plates.

The Xenolithic Rock

The xenolithic portion of the sill presents a striking appearance (Plate VI, fig. 1). In the pinkish weathered matrix are prominent large xenoliths of white quartzite, smaller dark amphibole-rich fragments and small black hornblendic " crystals ".

(*a*) *Quartzite xenoliths.*—The quartzite inclusions are definitely of sedimentary origin since bedding planes are preserved in them. Their length may reach a couple of feet, but usually they are about 9 inches long. They are roughly oriented, with their largest diameters parallel to the length of the intrusion. Quartzite inclusions of a diameter of only an inch or two are rare, and smaller sizes are not seen. Many of these inclusions, especially the smaller ones, have an oval or elliptical outline and appear to have been partly absorbed by the magma during its intrusion. Though the large inclusions have an irregular shape, their contacts are rounded but still sharp.

In thin sections, the quartzite xenoliths show no noticeable change from centre to margin. They are made up of a mosaic of weakly-

strained quartz grains with very subordinate intergranular cloudy felspar, mostly albite-oligoclase. The accessories are chlorite, chloritized biotite, clinozoisite and ore in negligible amounts. The quartzites into which the sill is intruded, in common with the rest of the country-rock quartzites, are a little richer in felspar and coarser in grain-size than the quartzite xenoliths.

At the direct contacts of the quartzite xenoliths with the matrix of the intrusion, signs of replacement of their quartz by the felspars of the intrusion are very imperfectly observed ; large clouded crystals of the groundmass penetrate irregularly into the adjoining quartz grains. Rare narrow tongues, 1 cm. in width, of the matrix of the sill intrude the quartzite inclusions for 3 cm. or so ; they taper at their ends and are apparently emplaced along weak planes. A characteristic feature of the contact is the occurrence of a dark basic rim of an aggregate of amphibole. This rim, about 0·25 mm. in thickness, is fairly permanent all round the xenoliths but is absent in a few places where a large felspar of the matrix appears to be starting to replace the quartz mosaic of the xenolith. The amphiboles of the rim are like others in the matrix.

(*b*) *Amphibolic xenoliths.*—The amphibolic xenoliths are much smaller in size than the quartzitic ones. The largest is about 6 inches in length, but the majority is around 2 inches or less. They appear as dark irregular patches and blotches (Plate VI, fig. 2). In the larger inclusions of this type sedimentary bedding (and not foliation) can be seen, though in thin section it is not recognizable. Under the microscope, these inclusions are found to be made up of dense aggregates of actinolitic amphibole prisms with ragged edges set with random orientation in a base of plagioclase similar to that of the matrix outside the inclusions. The amphiboles tend to be larger and sometimes darker at the outer margin of the inclusions. Accessory components are clinozoisite-epidote, sphene, and rare apatites ; no diopside is present. The assemblage and habit of these amphibolic xenoliths are not different from those exhibited by certain of the metamorphosed calc-silicate bands occurring elsewhere in certain migmatized patches of the Dalradian country-rocks of Donegal.

(*c*) *The Matrix and its Hornblendic "Crystals".*—The *matrix* between the xenoliths is formed of large plates of plagioclase (2–4 mm. in diameter), usually of very irregular outline, and large hornblendic "prisms" some centimetres in length, together with smaller plates of amphibole and biotite. The plagioclase is slightly sericitized, poorly twinned, and of average composition An_{20}—this increase in the albitic component compared with the plagioclase of the normal uncontaminated sill-rock may be related to the presence of the siliceous xenoliths. The plagioclase is extensively riddled with tiny quartz blebs, some of which resemble the quartz of myrmekite in appearance. Fine aggregates of small random amphibole prisms and biotite flakes similar to those of the normal sill rock are present in the matrix.

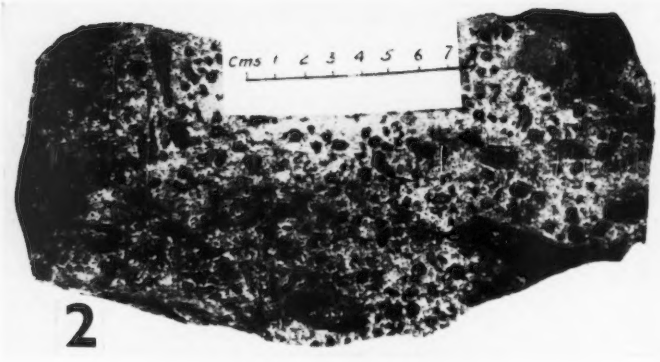
Accessory components are frequent; tiny epidotes, rather large sphenes and apatite occur, the last named being absent in the homogeneous part of the sill. The specific gravity of a large block of the hybrid rock devoid of quartzitic inclusions is 2·878.

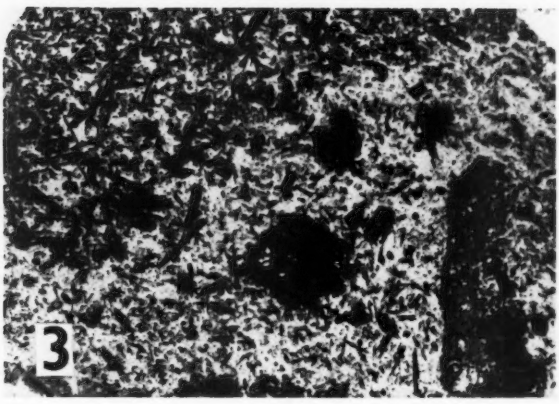
The *hornblendic "crystals"* that stud the matrix (Plate VI, figs. 2 and 3) reach 2 inches in length but are more often about an inch long. They usually have a well defined outline but thin sections reveal that they are commonly made up of very dense aggregates of flakes of several amphiboles and biotite. Biotite, with Z = Y dark greenish brown, X very pale yellow, definitely replaces the amphiboles. The latter are of composite nature. Their centres are of a brownish-green hornblende, now usually finely dusted, which passes outwards into actinolitic hornblende, then into actinolite, and then occasionally into colourless tremolite. This would indicate a progressive decrease in alumina, soda, and iron. The late varieties either build outer zones round the earlier ones or penetrate and replace them irregularly. In one case, a later actinolitic tremolite, while replacing the hornblende on the inside, also replaces the plagioclase matrix outside, leaving for a while its quartz blebs so that the amphibole receives a dentated margin. Biotite or its chloritic pseudomorph appears sometimes to have been formed as early as the actinolite and tremolite, and is perhaps sometimes even earlier than them, since straight thin flakes of biotite that cut the older hornblende cores are absent from the actinolitic and tremolitic coatings to these. Also, interlocking aggregates of biotite with a few hornblende relics are occasionally coated by actinolitic tremolite.

Discussion and Conclusions

From the general regional geology of the area, it is clear that the Tallabrista sill is a pre-metamorphic magmatic intrusion and that the xenoliths have retained their original relative positions in it. These xenoliths, like the sill-rock itself, have of course undergone some metamorphic changes but these have not been sufficiently intensive to destroy the primary relationships.

The sill is emplaced in quartzites. It is considered that the amphibolic xenoliths were originally impure limestones. It is known from the geological relationships of the surrounding country-rocks that limestone bands are present only in the semipelitic horizon that stratigraphically lies far below the massive quartzites into which the present sill is intruded. Further, the contacts of the sill with the quartzites appear to be sharp and clean-cut. The inclusions of both types, therefore, were not caught up in situ, and the sill-magma must have carried them from their respective sediments and transported them for some distance during its intrusion. The sudden appearance of these inclusions of different parent rocks almost clogging up the sill-channel suggests that they must have been concentrated and carried in one part of the invading magma, perhaps its spearhead





XENOLITHIC SILL AT TALLABRISTA.

which is conventionally considered to be richer in " volatiles ", etc. The oval outlines of the inclusions indicate that they have to some extent lost their corners to the enclosing magma. The absence of significant zonal structures, especially round the quartzitic xenoliths, indicates that such structures, if once formed, were completely destroyed as the xenoliths were rushed up in the moving magma, so that a fresh surface was always exposed to its action. Solidification was probably abrupt—as suggested by the chilled-like nature of the normal sill-rock —so that no final zonal structures were formed round the inclusions.

The amphibolic xenoliths were certainly not of epidioritic derivation ; they can reasonably be related to a limestone parent. They have undergone a certain amount of basification.

The matrix between the xenoliths is richer in mafic material than the normal portion of the sill, as is witnessed by the abundance of the large hornblende " prisms " in it. The origin of these hornblende " prisms " though clearly related to the presence of the xenoliths, is a matter for discussion. First, they might be interpreted as direct crystallizations from a magma contaminated by the absorption of limestone material. Second, they might be considered to be of porphyroblastic formation, drawing their material by diffusion from adjacent xenoliths. Lastly, they could be small fragments of the xenolithic limestone in which the process of basification and homogenization had been carried to extremes. The presence of rather coarser borders and fringes to some of the amphibolic xenoliths gives some support to the last suggestion.

Finally, it may be noted that the matrix with its hornblende " prisms " recalls certain of the appinites of the Scottish Highlands. The writer does not wish at present to join the discussion of this enigmatic rock-group but is content to present the facts observed in the Donegal xenolithic sill.

ACKNOWLEDGMENTS

The present work is part of a study carried out at the Imperial College with a grant from the Research Fund of Farouk I University, Alexandria, which the writer deeply acknowledges. He is indebted to Professor H. H. Read for his valuable advice and criticism.

EXPLANATION OF PLATE VI

FIG. 1.—Xenolithic sill, Tallabrista. The white inclusions are quartzite ; the hornblendic dark inclusions show less clearly. Scale is 1 foot divided into inches.

FIG. 2.—Matrix of the xenolithic part of the sill with some dark amphibolic inclusions. The small dark clots and prisms appear to have the outline of single idiomorphic crystals of amphibole. The photograph is of a weathered slab to bring out more clearly the amphibolic parts of the matrix.

FIG. 3.—Micro-photograph of the matrix (2 cm. × 3 cm.) of the xenolithic part of the sill. One corner of the figure covers the outer portion of an amphibolic xenolith, while elsewhere large amphibolic " prisms " or their cross-sections are dispersed in the matrix.

Faulted Permian Dykes in the Highlands

By G. P. Leedal

Abstract

In the Arkaig district of Inverness-shire there is a well-defined suite of camptonite-monchiquite dykes, and several of them have been observed to be displaced laterally along sinistral faults. This provides direct evidence of transcurrent faulting in Permian or post-Permian times. Similar faulting may have occurred along the major north-easterly fracture lines of the Highlands.

Introduction

A MAJOR tectonic feature of the Scottish Highlands is the north-east fault system (Anderson, 1942, pp. 86–98 ; Kennedy, 1946, pp. 55–7, fig. 4), the individual dislocations having been proved in most cases to be lateral-slip faults with sinistral displacements. Anderson (1905, p. 397 ; 1942, pp. 98–101) has considered them to be the result of an Armorican stress system involving north–south compression. There is considerable doubt regarding the age of the faulting. Kennedy (1946, p. 66) believes the main lateral movement of the Great Glen fault was accomplished before the Upper Carboniferous but does not exclude the possibility of up to five miles of lateral displacement in post-Carboniferous times. Normal faulting occurred during the Upper Mesozoic along the Great Glen fault (Horne, 1914, p. 69) and the parallel Helmsdale (Bailey and Weir, 1932) and Camasunary (Wedd, 1902) faults.

Evidence for the age of the transcurrent faulting is provided by the Arkaig district where camptonite dykes are cut and displaced along north-east crush-lines. In view of the importance of this evidence it is proposed to discuss it in some detail.

Occurrence and Age of the Camptonite-Monchiquite Dykes of the Arkaig District

The area described in this paper lies at the head of Loch Arkaig, 14 miles north-west of Fort William, Inverness-shire. It is composed of psammitic and pelitic schists of the Moine Series cut by a swarm of camptonite-monchiquite dykes that are similar to those occurring elsewhere in Scotland (Richey, 1939, pp. 416–19).

In the Arkaig area seventy occurrences of dykes have been mapped by the author. There are three major trends of the swarm, the most prominent being E. 10° S. ; the others are E. 25° S. and N. 70° E. The average width of the individual dykes is 3 feet and in several cases they occur in groups of two or more separated by thin screens of country rock. As many as twelve dykes, with an aggregate thickness of 36 feet, have been found in a distance of one-third of a mile.

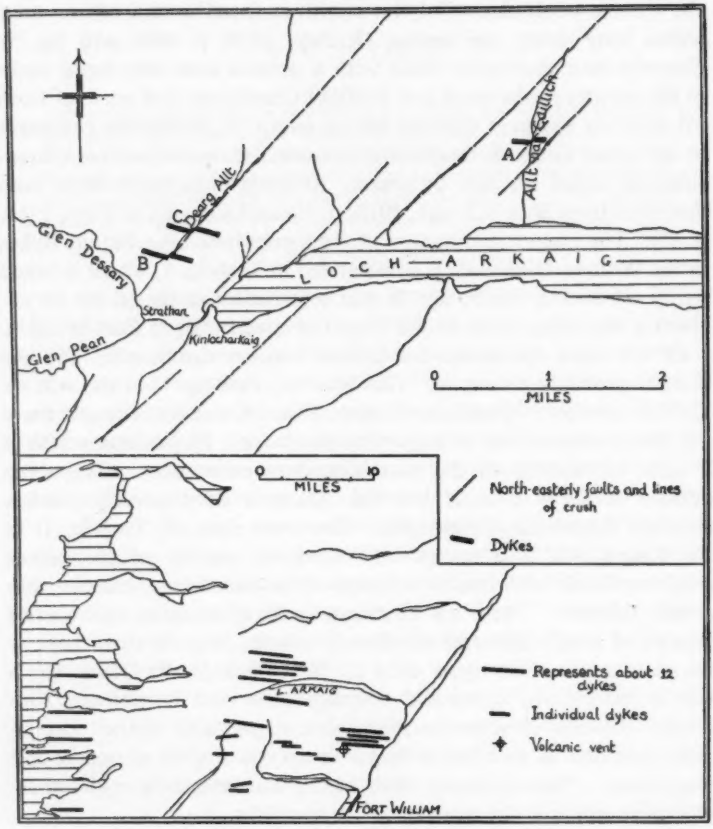
The Arkaig camptonite-monchiquite assemblage represents in part

the eastern continuation of the swarm mapped in the Morar area, where sixty dykes are known (Richey, 1939, p. 418, and fig. 5). Camptonite-monchiquite dykes with a general east–west trend occur in the country to the north and south of Glenfinnan and north of Loch Eil and it is apparent that the Morar swarm is continuous eastwards to the Great Glen. In north-west Inverness-shire and southern Ross-shire the dykes are rare or absent. Isolated occurrences have been described from Skye (Clough, 1910, p. 79) and Ross-shire (Flett, 1913, p. 79). The known distribution of the camptonite-monchiquite dykes in the Western Highlands is summarized in Text-fig. 1, which is based partly on Richey (1939, fig. 5) and information supplied by Mr. J. Hartley regarding dykes in the Glen Loy area north of Fort William.

Of the three dykes that are faulted two are camptonites and the third is probably a dolerite. The dyke (A, Text-fig. 1) in the Allt na Caillich consists of plagioclase, calcite, chlorite, and iron-ore and there are sparse phenocrysts of serpentinized olivine. Plagioclase, which is a sodic labradorite, is the most abundant constituent. This dyke appears to be a dolerite but the extensive decomposition makes accurate identification impossible. The lower dyke (B, Text-fig. 1) in the Dearg Allt is a camptonite consisting mainly of plagioclase and hornblende with smaller amounts of biotite, olivine, analcite, and potash feldspar. There are abundant ocelli of analcite, calcite, and crystals of plagioclase and hornblende coarser in grain than those in the groundmass. The upper dyke (C, Text-fig. 1) in the Dearg Allt is also a camptonite, composed of plagioclase and hornblende with smaller amounts of serpentinized olivine, augite, and biotite. It contains xenoliths up to 2 feet in length composed mainly of quartz and plagioclase. These minerals have been metasomatically replaced by spherulitic albite at the margins of the xenoliths.

The three dykes described above are considered to be typical members of the camptonite-monchiquite suite, this conclusion being based primarily upon their petrographic similarity with types occurring elsewhere in the Highlands (Flett, 1900, pp. 874–886 ; 1935, pp. 174–180 ; Thomas, 1924, pp. 380–2). Further, the east–west trend of the dykes is in agreement with the trend of the Morar camptonite-monchiquite assemblage. In the Arkaig district there are three other major suites of hypabyssal intrusions of Caledonian age, namely, lamprophyres (appinitic), which have a general N.N.W. to N.E. trend, dykes of trondhjemite-porphyrite, and lamprophyres, quartz-micro-diorites and porphyrites. The camptonite-monchiquite dykes are readily distinguishable in the field and in thin section from these Caledonian intrusions and have been observed to cut the appinites.

The question of the age of the camptonite-monchiquite dyke suite has been much discussed during the past fifty years. A summary of



TEXT-FIG. 1.—Above: Map of the Arkaig district showing displaced dykes, north-east faults, and lines of crush. Below: Map of the Western Highlands showing the known distribution of Permian dykes.

evidence and views has been given by Richey (1939, pp. 416–19), who regards the suite as Permian. Recently the whole question of Scottish Carboniferous-Permian volcanicity has been discussed by MacGregor (1948) and he has summarized the evidence concerning the age of the camptonite-monchiquite dykes both in the Highlands and Lowlands. He concludes that they are late Carboniferous or early Permian.

FIELD RELATIONS OF THE FAULTED DYKES

The map (Text-fig. 1) shows the position of the faulted Permian dykes in the Arkaig area and the main north-easterly trending fractures. The most prominent lines of crush are those in the Dearg Allt and

Allt Mhurlagain, the crush zone along the latter stream being locally up to 20 feet wide. The crush along the Dearg Allt probably represents the south-westerly continuation of the Strath Glass fault described from northern Inverness-shire (Hinxman, 1914, pp. 70–1), as has already been indicated by Kennedy (1946, fig. 4). Geikie's map of Scotland (1909) shows this fault reaching the sea near the head of Loch Nevis.

Another set of prominent crush lines of doubtful age trends east–west and is cut by camptonite dykes.

The dyke (A, Text-fig. 1) in the Allt na Caillich is 2 feet wide and trends E. 5° S. It is displaced laterally for 5 feet along a small sinistral fault trending N. 40° E. Dyke B is 2 feet in width and trends E. 15° S. It cuts part of the crush along a fault trending N. 40° E. and is therefore later than some of the faulting. The displacement of the dyke is 15 feet in a sinistral direction. Exposures in the stream, however, are insufficient to decide definitely whether this displacement is due to faulting or to swing of the dyke along the fault. In view of the unequivocal evidence provided by dyke C, which is displaced along the same line of faulting, it is considered that the former is the case. Dyke C, which occurs near the main waterfall of the Dearg Allt, is 13 feet wide and trends E. 25° S. It is displaced laterally along a sinistral fault trending N. 40° E. and hading 70° towards the east. The dyke is intensely crushed along the fault and horizontal slickensides occur on the fault plane.

Conclusions

If the dykes are of Permian age then their displacement provides direct evidence for Permian or post-Permian transcurrent faulting along north-easterly trending fractures. There is thus a strong presumption that some of the major north-easterly faults of the Highlands may have similarly moved or were still moving in Permian or post-Permian times. The faulting of the Arkaig dykes is in all probability of Permian age originating under late Hercynian stresses and being posthumous along pre-existing faults.

I should like to thank Professor W. Q. Kennedy for his help in the preparation of this paper.

REFERENCES

Anderson, E. M., 1905. The dynamics of faulting. *Trans. Edin. Geol. Soc.*, viii, 387–402.

—— 1942. *The dynamics of faulting*. Edinburgh.

Bailey, E. B., and Weir, J., 1932. Submarine faulting in Kimmeridgian Times : East Sutherland. *Trans. Roy. Soc. Edin.*, lvii, 429–467.

Clough, C. T., 1910. *In* The geology of Glenelg, Lochalsh, and south-east part of Skye. *Mem. Geol. Surv.*

Flett, J. S., 1900. The Trap Dykes of the Orkneys. *Trans. Roy. Soc. Edin.*, xxxix, 865–905.

FLETT, J. S., 1913. *In* The geology of central Ross-shire. *Mem. Geol. Surv.*
—— 1935. *In* The geology of the Orkneys. *Mem. Geol. Surv.*
HINXMAN, L. W., 1914. *In* The geology of the country round Beauly and Inverness. *Mem. Geol. Surv.*
HORNE, J., 1914. *In* The geology of the country round Beauly and Inverness. *Mem. Geol. Surv.*
KENNEDY, W. Q., 1946. The Great Glen fault. *Quart. Journ. Geol. Soc.*, cii, 41–72.
MACGREGOR, A. G., 1948. Problems of Carboniferous-Permian volcanicity in Scotland. *Quart. Journ. Geol. Soc.*, civ, 133–152.
RICHEY, J. E., 1939. The dykes of Scotland. *Trans. Edin. Geol. Soc.*, xiii, 393–435.
THOMAS, H. H., 1924. *In* The Tertiary and Post-Tertiary geology of Mull, Loch Aline, and Oban. *Mem. Geol. Surv.*
WEDD, C. B., 1902. *In* Summary of progress for 1901. *Mem. Geol. Surv.*

Tertiary and Pleistocene Sediments from the Cape Verde Archipelago

GERALD M. PART

ABSTRACT

Tertiary and Pleistocene sediments, largely calcareous, and certain metamorphosed limestones, are described from the Cape Verde Archipelago.

THE Walter Child Collection in the British Museum (Natural History) (BM 1915/130/) contains a number of specimens of Recent and Tertiary limestones and conglomerates from S. Vicente, S. Tiago, and Brava, and also some metamorphosed crystalline limestones from Fogo which throw some light on the vexed question of the age of these particular rocks.

All the unmetamorphosed sediments are essentially similar in type, being beach or dune sands and pebble beds composed of subangular or rounded fragments of various calcareous organisms which make up to 80–90 per cent of the rock. The remainder is volcanic detritus, grains, and pebbles of lavas and of minerals derived from them. The chief organic constituent is the calcareous alga *Lithothamnion*, accompanied by fragments of mollusca, foraminifera, and occasional echinoid spines (Part, 1930).[1] The detrital grains are cemented either by a fine calcareous mud or by secondary calcite. This latter begins as a thin skin surrounding each grain, composed of radially disposed calcite prisms orientated normal to the grain surface. In the Recent and Pleistocene examples this process has not proceeded far and on the whole these rocks are porous and poorly bonded, but in the Tertiary examples cementation is more complete and the interstices have been filled in with a mosaic of granular calcite to produce a compact white or cream-coloured rock speckled with dark grains of volcanic material and lighter fragments of mollusca.

The formation of calcareous beach-deposits of this nature is still proceeding in the area at the present day and the process has been described by Crossland (1905, p. 184).

Though not apparent under the microscope these limestones are comparatively rich in phosphate, derived no doubt from organic sources, the importance of which will be apparent when we come to consider the crystalline limestones of Fogo.

(*a*) *Pleistocene and Recent Sediments.*—Typical of these is (BM

[1] In describing the Quest Expedition specimens I recorded the presence of coral. Re-examination of this collection has shown that this identification is incorrect and that these limestones (Q–A 22) are similar to other Recent examples from S. Vicente.

1915/130/591) near Bathing place, Mindello, S. Vicente (Text-fig. 1 A). In addition to the usual organic debris this contains a representative selection of the igneous minerals of the island—titanaugite, green and brown hornblende, olivine, magnetite, melanite, sanidine, plagioclase, and analcite. Lava fragments include various olivine-basalts and camptonite. (BM 1915/130/647) South shore, Mindello, similar to the above contains in addition perovskite derived from the melilite-basalt of M. Verde.

(BM 1915/130/608) West end of Porto Grande, Mindello, is a black sand composed of volcanic material, iron ores and pyroxene and is probably a " heavy residue " naturally panned by wave-action.

The composition of a number of these Recent deposits is shown in Table 1, together with that of two of the Tertiary specimens and a

TABLE I

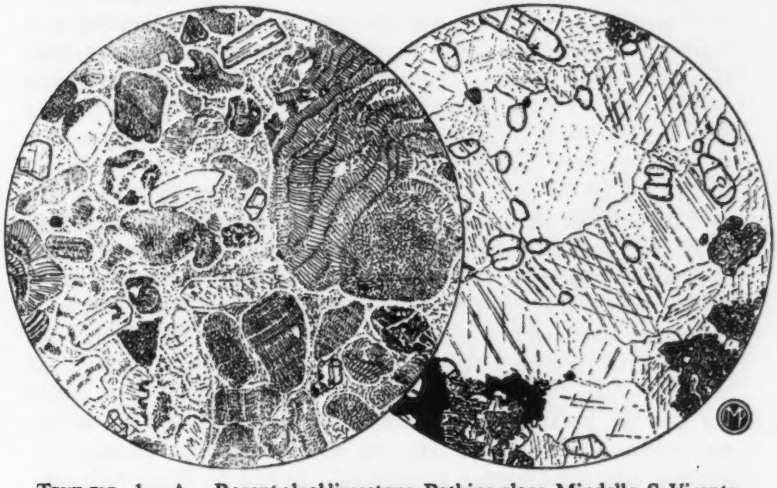
	591	Q-A 22	46282	2034	198	226	608	E
Feldspar .	0·1	0·4	—	—	—	0·2	—	2·0
Pyroxene .	3·6	4·2	6·4	0·2	4·0	1·5	34·1	43·0
Amphibole .	0·2	0·6	0·8	—	—	0·1	—	6·0
Olivine .	0·6	0·3	0·7	0·8	1·3	0·6	2·4	3·5
Ores . .	0·3	0·2	0·2	0·5	0·6	0·5	61·3	43·0
Rock fragments .	3·4	0·8	7·2	13·1	2·5	8·4	1·2	2·5
Total igneous	8·2	6·5	15·3	14·6	8·4	11·3	99·0	100·0
Calcareous .	91·8	93·5	84·7	85·4	91·6	88·7	1·0	—

BM 1915/130/591. Recent limestone, Mindello, S. Vicente.
BM 1927/1245/Q-A 22. Recent limestone, Salamanza Bay, S. Vicente.
46282. Recent limestone, Mindello, S. Vicente (Dept. Mineralogy and Petrology, Cambridge).
2034. Recent beach sand, Confetal Bay, Gran Canaria (Sedgwick Museum, Cambridge).
BM 1915/130/198. Miocene limestone, Praia, S. Tiago.
BM 1915/130/226. Miocene limestone, 3½ km. S.W. of Praia, S. Tiago.
BM 1915/130/608. Beach sand, Porto Grande, Mindello, S. Vicente.
E. Beach sand, Porto Grande, Mindello, S. Vicente (Ermert, 1936).

comparable beach-sand from Gran Canaria, for which last I am indebted to Dr. M. Black of the Sedgwick Museum, Cambridge.

(*b*) *Tertiary limestones and Pebble-beds.*—These are found intercalated in the Tertiary volcanic sequence and in S. Tiago have been proved to be of Miocene age. In S. Nicolão the sequence is similar, but the palaeontology has not been published in detail. (BM 1915/130/226) 3½ km. S.W. of Praia, may be taken as typical of the Miocene

of Southern S. Tiago where it forms a well-marked white band among the dark " basalts " (Bebiano, 1932, pp. 101, 102). Among its 10 per cent of igneous detritus are grains of analcitite, limburgite, analcite-basanite, olivine-basalt, and camptonite, with fragments of olivine, titanaugite, brown hornblende, and magnetite. There are no minerals derived from the phonolites. (BM 1915/130/233) 4 km. S.W. of Praia consists of igneous and organic grains set in a matrix of fine calcareous mud with larger shell-fragments and pebbles of olivine-basalt and of rolled fragments of *Lithothamnion*, but in addition the thin section



TEXT-FIG. 1.—A. Recent algal limestone, Bathing place, Mindello, S. Vicente, C. Verde Is. BM 1915/130/591. × 40.
B. Metamorphosed limestone, 3–5 km. up R. Trinadade, Fogo, C. Verde Is. BM 1915/130/785. × 20.

shows a pebble of a very fine-grained hard white limestone. This consists of a very fine calcareous mud containing minute shell-fragments, *Globigerina*, and other foraminifera, radiolaria, sponge-spicules, and round grains of phosphate (possibly decomposed glauconite). It is quite unlike any other Tertiary limestone in the Collections and would seem to be chalk. This raises an interesting problem, as no Upper Cretaceous has been hitherto reported from any of the islands. Stahlecker (1935) has established the Neocomian age of the Lower Cretaceous cephalopod fauna of Maio and Aptian rocks are believed to occur in this island. If this pebble is of Upper Cretaceous age, it can only have reached its present situation (*a*) by denudation of an Upper Cretaceous mass exposed in Miocene times and since covered up by later volcanic activity or (*b*) from an agglomerate containing ejected blocks of the Cretaceous platform underlying the island. The

relatively unaltered condition of the rock suggests the first explanation as more probable.

(*c*) *Metamorphosed Limestones.*—In S. Tiago certain of the sedimentary series have been converted into white or grey marbles. An early stage is illustrated by (BM 1915/130/258) Ribeira S. Jorge, 5 km. N. of Praia in which the organic structures are still recognizable. In more advanced cases of alteration all such traces have been lost and the result is a fine-grained saccharoidal marble. (BM 1911/1616) is a white crystalline rock crowded with fragments of limburgite identical with (BM 1920/668/19). There is similar material in the Darwin (H.M.S. *Beagle*) Collection (Department of Mineralogy and Petrology, Cambridge), from the entrance to Porto Praia, opposite Quail I. (Darwin, 1844). This probably comes from a Recent beach deposit overlain by a Recent flow and the limestone at the contact after recrystallizing in radial aggregates of aragonite has subsequently inverted to calcite leaving " ghosts " of the original texture. Similar is (Q – A 25) an ejected block from Viana Crater, S. Vicente, but here the original aragonite is still present. There is a legend handed down by a succession of early continental writers that several of the islands are composed largely of Pre-Cambrian " basal complex ". Bebiano categorically denies this, as regards S. Vicente and S. Nicolão and makes no mention of early rocks in any of the other islands. He records certain schists in Boa Vista as Tertiary lavas and ashes involved in local tectonic disturbances and as regards Fogo, Furon (1935) has put the matter in a nutshell—" Du primaire nous ne savons strictement rien. On pourrait peut-être lui attribuer certains des calcaires crystalline à mica et amphibole de l'Ile de Fogo, mais sans aucune antre raison que leur aspect ancien."

Babiano, unfortunately, does not appear to have visited Fogo in person, but specimens in the Child Collection enable us to carry the inquiry a stage further, though it is not yet possible in the absence of field evidence to give a definite age to these rocks. They all come from stream exposures near S. Filipe on the west coast, where Friedlander (1913) notes a pink crystalline limestone from M. Almada :

(*a*) R.S. Filipe, 1½–2 km. up, at 150–200 m.

(*b*) R. Trinadade, 3–5 km. up, at 300–500 m.

(*c*) M. Almada and R. " Montindor " (a term of Friedlander's which may be R. Pico of the Portuguese Survey) at 300 m.

(BM 1915/130/845–6) R. " Montindor " are coarse buff or grey rocks of gneissose appearance speckled with dark green pyroxene, magnetite, and biotite. In thin-section they show a mosaic of calcite, patches of spongy green pyroxene (X green > Y green > Z yellowish-green, Z ∧ c 39°), magnetite, golden brown biotite ($\beta = 1{\cdot}647$, 2V

$= 16°$ (−)) and streaks rich in rounded prisms of apatite ($\omega = 1{\cdot}642$, $\epsilon = 1{\cdot}638$).

The R. Trinidade specimens are finer-grained saccharoidal marbles white, buff, or pink in colour which yield an insoluble residue of pyrites (or haematite pseudomorphs after pyrites), less common pale biotite (mean R.I. = 1·585) and in the case of (BM 1915/130/785) spongy green pyroxene and magnetite. Both (784) and (785) are rich in apatite (Text-fig. 1 B). The Collection also includes a number of pebbles collected from the limestones (BM 1915/130/791, 793, 795). These include coarse " clots " of augite-hornblende, augite-magnetite, altered nepheline-syenite, olivine-basalt or basaltic ash, all of which can be matched in the igneous sequence of the island. It is clear that the spongy pyroxene-biotite-magnetite patches in the limestones represent more altered grains of detrital volcanic material whilst the apatite is derived from finely disseminated organic phosphate and we can definitely rule out any Pre-Cambrian age for these limestones. It is not possible at present to say whether they are Tertiary or Pleistocene, but it may be significant that Friedlander records Recent raised beaches at 280 m., 350 m., and 500 m. and more than one such deposit may be involved. The syenite pebble may have some connection with a nepheline-syenite (not unlike that of Pedras Brancas, S. Vicente) known to occur on or near M. Almada (BM 1915/130/851).

I am indebted to the Trustees of the British Museum (Nat. Hist.) and the Keeper of Minerals, Dr. Campbell Smith, and to Professor Tilley of Cambridge for access to the Collections in their charge.

REFERENCES

(1) Bebiano, J. B., 1932. A geologia do Arquipelago de Cabo Verde. *Serv. Geol. de Portugal.*

(2) Crossland, E., 1905. Oecology and deposits of the Cape Verde marine fauna. *Proc. Zool. Soc.*, i, 170–186.

(3) Darwin, C., 1844. Voyage of the " Beagle ".

(4) Ermert, H., 1936. Ein beitrage zur Kenntnis der gesteine der Kapverdischen Inseln Sao Vicente und Sal. *Chemie der Erde*, x, 155–186.

(5) Friedlander, I., 1913. Beitrage zur Kenntnis der Kapverdischen Inseln. Berlin.

(6) Furon, R., 1936. Notes sur la Paléogeographie de l'Ocean Atlantique. I : La Géologie de Cap Verte. *Bull. Mus. Nat. Hist.*, vii, 4, 270–4.

(7) Part, G. M., 1930. " Quest " Expedition Report, Chap. 2. Rocks of St. Vincent. British Mus. (Nat. Hist.), London.

(8) Stahlecker, R., 1935. Neocom auf der Kapverden Inseln Maio. *Neues Jahr. Min. Geol. etc., Abt. B*, lxxiii, 265–301.

CORRESPONDENCE

THE DENT LINE IN LANCASHIRE

SIR,—The recent announcement (von Estorff, 1950, p. 1448) that the deep test on the Lancashire coast, 2½ miles west of the earlier one at Formby, has revealed the Carboniferous to lie nearly 4,000 feet structurally higher in the new boring than in the old, seems to support my view (Turner, 1949, p. 295) that the Dent Line passes southwards through the Formby area beneath the New Red cover. Mr. H. R. Lovely (1950, p. 541) on behalf of Mr. P. H. N. White, appears to agree that gravity results are not irreconcilable with this view. He appears troubled, however, by the necessity of a rather sharp bend southwards of the Dent Line to reach Formby. Such bends, nevertheless, are present elsewhere in the Line, notably in the Stainmore country and where the Line crosses the Craven Faults. The hypothesis of the Line's continuation into South-West Lancashire seems to relate the fascinating results of the deep tests to the broader scheme of Variscan tectonics in Northern England in an intelligible fashion.

J. SELWYN TURNER.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF LEEDS.
24th November, 1950.

REFERENCES

LOVELY, H. R., 1950. *In* Discussion *of* " Gravity Data obtained in Great Britain by the Anglo-American Oil Company Limited ". *Quart. Journ. Geol. Soc.*, cv, p. 540.

TURNER, J. S., 1949. The Deeper Structure of Central and Northern England. *Proc. Yorks. Geol. Soc.*, xxvii, p. 280.

VON ESTORFF, F. E., 1950. Petroleum Developments in Europe in 1949. *Bull. Amer. Assoc. Pet. Geol.*, xxxiv, p. 1429.

RED SEA RIFTING

SIR,—It is all too seldom that geologists associated with oil exploration lif a corner of the curtain of secrecy and from their hoard of scientific information cast out a few crumbs to the waiting academic sparrows. Professor Tromp's paper (*Geol. Mag.*, Nov.–Dec., 1950, p. 385) is therefore welcome, especially now that Professor Gregory's book is thirty years old. But what a strange list of references : seven Tromps, two Germans, and an American, the last three only for publications of a purely general nature. The reader would hardly realize that British, Egyptian, and French geologists have been working on these problems for fifty years, and between them long ago produced a picture which any amount of drilling can merely touch up.

After reading Professor Tromp's paper I turned to such few works by members of the Geological Survey of Egypt as are readily to hand on my own shelves and found, as I thought, that nearly every point made in the first three parts of the paper (not the fourth, purely speculative part) is to be found there, published from twenty-five to fifty years ago. For instance :—

1. Progressive transgression from the north during the Mesozoic and Lower Eocene " (Tromp, 1950) ". This was clearly enunciated by Hume, 1916 (Oilfields Region Memoir, p. 52), and is obvious from Hume's work over fifty years.

2. Doming and faulting with consequent unconformable overstep of the Middle Eocene across denuded Cretaceous in the north. How can the author put " Tromp, 1949 " against this ? Has he never walked over the Abu Roash dome and especially the Jeran el Ful ridge with Beadnell's splendid memoir of 1902, where the Middle Eocene unconformity is set out so clearly in text, sections, and map ?

3. Northward recession of the sea after the Oligocene and northward migration of facies " (Tromp, 1950) ". This was clearly stated by Beadnell

in 1905 (Fayum memoir, p. 71) and again is obvious from the accumulated work of Hume, Beadnell, and others.

4. Large erosional hiatus at base of the Miocene (Middle Miocene ?) in the Gulf of Suez, indicating strong tectonic movements followed by a long period of erosion in pre-Miocene time " (Tromp, 1949 and 1950) ". Hume in 1916 (Oilfields Region Memoir, p. 40) traced in detail the great unconformity at base of the Middle Miocene as shown by the overstepping *Pectan submalvinae* Beds across all older formations including Archaean, and Beadnell (1924, Qosseir-Wadi Ranga Memoir, p. 32) stressed the importance of these movements.

5. Post-Miocene N.W.–S.E. faults cutting across the grain of the older folds. Pointed out by Moon & Sadek, 1921 (North Sinai Memoir, pp. 52–3).

6. Probable continuation of the movements to present day. Stated by Beadnell, 1924 (Qosseir-Wadi Ranga Memoir, p. 32).

7. Middle Pliocene transgression in Gulf of Suez region. Observed by Moon & Sadek, 1921 (op. cit., p. 53).

It is to be hoped that Professor Tromp is aware of all this literature and much more, if, as he promises, he is to give us a " compilation of the macro-stratigraphy of Egypt ". The astonishing second sentence of his opening paragraph raises grave doubts.

Three points put forward seem new and important :—

A. The existence of Jurassic Nubian Sandstone in Southern Egypt.

B. That the Red Sea was closed at both ends during the gypsum period. If so the existence of beds with *Barbatia*, *Venus*, *Diplodonta*, and *Corbula* in the gypsum is difficult to account for.

C. That Egypt as a whole was rising continuously throughout the Miocene, Pliocene, and Pleistocene. This seems difficult to reconcile with the well-known Upper Pliocene transgression to 180 m. above present sea-level in the Nile Valley.

May we have the evidence for A and the explanations of how the difficulties mentioned under B and C are to be disposed of ?

W. J. ARKELL.

CAMBRIDGE.
17th December, 1950.

LINEATION IN SCHISTS S.E. OF THE GREAT GLEN

SIR,—In 1937 I published (*Quart. Journ. Geol. Soc.*, xciii, 581–620) the first results of a study of the structural petrology of some Moine Schists. These results showed that the well-known " direction of stretching " (lineation) marked a *b*-axis of the fabric and pointed to the conclusion that " the Moine Schists were brought to their present state of regional metamorphism by a deformation acting along approximately south-west and north-east lines ". At that time my attention was mainly directed to the area north-west of the Great Glen, but study of the existing maps and literature had already convinced me that a similar significance could be attached to much of the lineation in rocks south-east of the Glen, not only in the Central Highland Granulites but also, in part, in rocks mapped as Dalradian. On the basis of an examination of a few isolated specimens, I ventured to include in a " General map of lineations believed to represent *b*-axes " (ibid., p. 594, Fig. 5), two further groups of symbols, one around Strath Spey and another near Struan and Kinloch Rannoch. The recent " Notes " by Dr. D. B. McIntyre (*Geol. Mag.*, lxxxvii, 1950, 331–6, 427–432) now afford interesting detailed evidence in confirmation of this conclusion. " The direction of movement is clearly perpendicular to the lineation and not parallel to it, as Hinxman assumed. The ' striping ' is a *b*-lineation." Dr. McIntyre also concludes that in his specimens the sense of movement was towards the south-west. On the basis of our present (imperfect) knowledge of the fabric of the schists of the Northern Highlands as a whole I would have arrived at the

opposite conclusion, for the general trend of arcuation of the prevailing south-easterly lineation, from more nearly W.–E. in the extreme north to more nearly N.–S. in the south, would seem to accord best with the assumption of movement *from* the south-west.

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18th December, 1950.

REVIEWS

AN OUTLINE OF THE GEOLOGY OF KENYA. By S. M. COLE. pp. xiii + 58. Pitman, 1950. Price 6*s*.

This little book is written for the general public living in Kenya, in the hope that they may become interested in the basic facts of geology and look at their country with eyes that see something of the past history of the area in the rocks. For others living outside Kenya, Chapter 5 will be useful in giving in concise form the succession of climatic changes and deposits of Quaternary and Recent age, worked out largely by Dr. Leakey.

It is hoped that this book may have a wide sale throughout Kenya, for it is through the influence of such works as this that valuable finds which otherwise would be lost may be brought to the notice of the authorities.

W. B. R. K.

A PRACTICAL HANDBOOK OF WATER SUPPLY. By FRANK DIXEY. pp. xxxvi + 573, with 133 figures and 6 maps. Allen and Unwin : Thomas Murby. 2nd edition, 1950. 35*s*.

This edition of Dr. Dixey's well-known book on water supply is largely a reprint of the 1931 edition with a number of references to recent work at the end of each chapter, so that the reader can bring the work up-to-date himself. That Dr. Dixey is well aware of the recent developments of geophysical methods and modern drilling technique is shown in the preface and in the additional bibliographies, and it is a pity these could not be incorporated in the main text.

The reproduction of the 1931 text when dealing with costs (e.g. on page 456) may be rather misleading at the present time. Nevertheless, it is good to have this authoritative book again available.

W. B. R. K.

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